Hangman (Latah) Creek
Fecal Coliform, Temperature, Total Phosphorus and Turbidity Total Maximum Daily Load

Water Quality Improvement Report

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Cover photo by Walt Edelen, Spokane County Conservation District: Hangman Creek in the canyon-like reach north of Keevy Road.

Hangman (Latah) Creek
Fecal Coliform, Temperature, Total Phosphorus and Turbidity
Total Maximum Daily Load

Water Quality Improvement Report

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Waterbody No. WA-56-2040, Rock Creek

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Abstract

This Water Quality Improvement Report or Total Maximum Daily Load (TMDL) report was a coordinated effort of the Spokane County Conservation District, the Washington State Department of Ecology, local landowners, agencies, organizations, and citizen groups.

Hangman (Latah) Creek has been listed on the states list of impaired waterbodies (the 303(d) list) for fecal coliform (FC), pH, temperature, dissolved oxygen, and turbidity. It is also known to contribute phosphorus to the Spokane River and Lake Spokane which are listed for dissolved oxygen (DO). The Spokane River DO TMDL sets limits on how much phosphorus can come from Hangman Creek.

The Clean Water Act requires states establish a TMDLs for each waterbody and parameter on the 303(d) list. This report includes an analysis of how much of fecal coliform, heat, turbidity and phosphorus Hangman Creek and its tributaries can assimilate and strategies for how to meet those loads. This TMDL does not address dissolved oxygen or pH impairments in the watershed.

Six wastewater treatment facilities and three entities regulated for stormwater receive wasteload allocations to control point source pollution. Nonpoint source pollution is controlled by establishing load allocations geographically throughout the watershed.

This report emphasizes Best Management Practices (BMPs) and education that target continuing problems such as the high fecal coliform bacteria, erosion and lack of streamside vegetation. The BMPs, and other alternatives discussed in this improvement plan should help to reduce all parameters on the 303(d) list.

The Hangman Creek watershed is a cross-border watershed with approximately 35% in Idaho. Water quality activities on the Coeur d'Alene Indian Reservation and on Idaho lands will be important to the success of this water quality improvement project.

Acknowledgements

This report provides a summary of water quality sampling completed on the Hangman (Latah) Creek Watershed. The work was funded by the Washington State Department of Ecology, and the funds came from both the Hangman Creek Watershed Management Plan (WRIA 56) and through a Centennial Clean Water Fund Grant for the Hangman Creek TMDL assessment, grant number G0400196. Charlie Peterson, Dan Ross, Amy Voeller, and Jennifer McCall spent many hours in the field setting up the sampling sites, surveying the cross-sections, and organizing the field equipment. Walt Edelen helped with the report editing and review. The outcome of this report, including many of the ideas and suggestions, can be directly associated to the significant help from several watershed residences.

Bill Sayres was instrumental in forming one of the first meetings with small-scale landowners along Hangman Creek. We should be unworthy of civilities if we failed to say that Mr. Sayres was a gentleman in the fullest sense of the term, and we were indeed most fortunate to be invited to his delightful house for the meeting.

Charlie Johnson provided insight to many of the issues in the watershed and was at the forefront in organizing meetings involving livestock owners in the watershed. Charlie Johnson is a gentleman of leisure and culture, and possesses a fund of information concerning the issues and history of the area. Charlie’s information, which is of absorbing interest to those who desire to listen, was of vast use at our meetings.

Pat and Jennie Kane provided valuable insight to our issues from the prospective of long-time farmers, and are an example of how the local producer makes not just a living, but also a livelihood in the Hangman Watershed. Their livelihood is tied to where the rich soil and warm sun aid their efforts in the direction of agriculture, and have been rewarded with large crops of wheat, peas, and other commodities raised in the area.

Penney Tee provided a mix of intelligent and industrious class to our meetings. She was the blending of a science teacher and farmer that could discuss issues that required an understanding of both. Penney was an exceedingly affable and courteous member of our committee.

Micki Harnois bestowed upon our committee the insight of the many small towns in the watershed. Micki symbolized many of the characteristics of the small towns she represents, and my arrival in these small towns was made exceedingly pleasant by the numerous and flattering courtesies of the citizens.

Cathy McBeth brought to the committee meetings insights from a newcomer to the area with the ambition and resources to try new and innovative ideas in working the land. Working with Cathy was one of the most agreeable and noteworthy experiences of many meetings during this project.

Many thanks to the watershed agencies that provided input and ideas; Dee Bailey with the Coeur d'Alene Tribe, Reanette Boese with Spokane County, and Bill Rickard with the City of Spokane.

I would like to thank the Town of Fairfield, which made our meetings exceedingly pleasant, with the atmosphere of this locality being represented as serene and transparent. It is a busy town and is characterized by a spirit of enterprise. A considerable acreage of wheat and other cereals is raised in this vicinity, and the future of this progressive little town is sure to be prosperous.

Dedication

This report is dedicated to Wayne Skertich (1946 – 2005) of Jardine, Montana. Wayne was a craftsman, a river enthusiast, and musician who tried to improve the natural environment for future generations. His ideas should be reflected in the goals of not only this watershed TMDL plan, but also in all TMDL plans; the important things in life are what we pass on to our friends and future generations. Wayne canoed the entire length of the Yellowstone River. There is a lot to be learned from Wayne.

Executive Summary

What is a Total Maximum Daily Load (TMDL)?

The Clean Water Act established a process to identify and clean up polluted waters. Each state is required to have water quality standards designed to protect, restore, and preserve water quality. Every two years, states are required to prepare a list of waterbodies that do not meet water quality standards. This list is called the 303(d) list.

The Clean Water Act requires that a Total Maximum Daily Load or TMDL be developed for each of the waterbodies on the 303(d) list. A TMDL identifies how much pollution needs to be reduced or eliminated to achieve clean water. Then the Washington Department of Ecology (Ecology), local governments, agencies, and the community develop a strategy to control the pollution and a monitoring plan to assess effectiveness of the water quality improvement activities.

Why is Ecology Conducting a TMDL Study in this Watershed?

Hangman Creek (also known as Latah Creek) is a trans-boundary watershed that begins in the foothills of the Rocky Mountains of northern Idaho, extends over the southeastern portion of Spokane County, Washington (Figure 1), and is a tributary to the Spokane River. It encompasses over 689 square miles (approximately 430,000 acres). The watershed is dominated by dryland farming, but like other eastern Washington watersheds, is experiencing increases in urbanization and changes in land use practices. The TMDL evaluation is limited to the 446 square miles of watershed within Washington.

Ecology and the Spokane County Conservation District (SCCD) are conducting a TMDL because Hangman Creek was identified on the 1998 303(d) list of impaired waters for not meeting state water quality standards for fecal coliform, dissolved oxygen, pH, and temperature. Hangman Creek and several of its tributaries (Little Hangman Creek, Rattler Run Creek, and Rock Creek) were also included on the 2004 303(d) list of impaired water for not achieving state water quality standards for fecal coliform, dissolved oxygen, turbidity, and temperature. The results of this TMDL study have identified additional water quality impairments that are proposed for the 2006/2008 303(d) list.

In addition to developing TMDLs specific to the Hangman Creek watershed, a phosphorus load allocation has been recommended for Hangman Creek by the Spokane River/Lake Spokane Dissolved Oxygen TMDL study. The Spokane River and Lake Spokane exhibit depressed dissolved oxygen (DO) levels during low flow in the summer months. Phosphorus loads from Hangman Creek and other sources in the Spokane River basin contribute to algae growth in the lake that eventually depress oxygen levels.

Goals and Objectives

The goal of this TMDL is to develop a plan to meet water quality standards for fecal coliform bacteria, temperature, and turbidity in Hangman Creek and its tributaries and meet phosphorus load allocations set by the Spokane River Dissolved Oxygen TMDL (Ecology, 2007). The following technical analysis and implementation strategy will accomplish this goal by:

1. Characterizing fecal coliform bacteria, heat, suspended sediment, and phosphorus loading from various parts of the basin.
2. Coordinating phosphorus TMDL load targets for the Spokane River dissolved oxygen TMDL with the Hangman Creek phosphorus TMDL targets.
3. Incorporating previously conducted temperature modeling work into a temperature TMDL.
4. Setting of total maximum daily load (TMDL) allocations on fecal coliform, total phosphorus, temperature, and suspended sediment/turbidity.
5. Outlining an implementation strategy.

Study Methods

Ecology used field data from historical and current studies conducted by the SCCD and Ecology to develop this TMDL. Most of the historical data was collected in the 1990's and early 2000's. Recent sampling by the conservation district for the development of this TMDL included sampling Hangman Creek and its tributaries at 19 sites. Sampling was from December 2003 through August 2004.

In 2002, Hardin-Davis, Inc. monitored and modeled temperature for a separate planning process. The model used was the Stream Network Temperature Model (SNTEMP).

Statistical tests were run using WQHYDRO (Aroner, 2007) and Microsoft® Office Excel (2003) software. Multiple regression analyses were run using an analytical method by Cohn (1988) with SYSTAT software. The Watershed Analysis Risk Management Framework (WARMF) model was run with software provided through the USEPA Office of Environmental Research and originally developed by the Systech Corporation (Systech, 2001).

TMDL Analyses

Fecal coliform

The Statistical Rollback Method (Ott, 1997) was used to determine if the FC distribution statistics for individual sites meet the water quality criteria in the Hangman Creek watershed.

The TMDL technical evaluation of the Hangman Creek watershed demonstrated that contact recreation is impaired in most areas that were investigated and that fecal coliform (FC) load reductions are necessary. The estimated load allocations (LA) and wasteload allocations (WLA) are shown in Table FC4. Most of the FC load sources are nonpoint in nature and require load allocations. The point sources in the basin are assigned wasteload allocations based on their NPDES permit limits, or on adjusted permit limits if water-quality based limits are necessary.

Table ES1. Fecal coliform load allocations and wasteload allocations for sites and point sources in the Hangman Creek watershed.

Hangman Creek Reach, Point Source, or Tributary	Listing ID	WLA or Load Allocation (cfu/day)	Current Load (cfu/day)	Target Reduction (%)	Target Basis WLA/LA WQ criterion
Hangman Creek at State Line	41992	5.6 x10^{11}	2.0 x 10^{12}	72%	10% > 200
Little Hangman Creek	41994	5.6 x10^{10}	1.7 x 10^{11}	67%	10% > 200
Tekoa WWTP		1.2 x 10^{9}	3.9 x 10^{9}	70%	NPDES permit
Hangman Creek at RM 53.8	6726	6.2 x10^{11}	2.2 x 10^{12}	72%	10% > 200
Hangman Creek at Fairbanks Road	46497	2.4 x10^{11}	5.4 x 10^{11}	56%	10% > 200
Hangman Creek at Spring Valley	46493	2.8 x10^{11}	8.0 x 10^{11}	65%	10% > 200
Hangman Creek at Marsh Road	45306	3.3 x10^{11}	4.9 x 10^{11}	32%	10% > 200
Cove Creek	45629	1.3 x10^{9}	6.0 x 10^{9}	79%	10% > 200
Unnamed Tributary at Griffith Road	45553	3.0 x10^{8}	4.1 x 10^{8}	25%	10% > 200
Unnamed Tributary at Roberts Road	45110	1.5 x 10^{8}	3.0 x 10^{8}	61%	10% > 200
Hangman Creek at Roberts Road	45242	5.1 x 10^{11}	4.0 x 10^{11}	27%	10% > 200
Hangman Creek at Bradshaw Road	16863	6.8 x 10^{11}	1.7 x 10^{12}	60%	10% > 200
Rattler Run at Mouth	45310	2.3 x10^{9}	1.5 x 10^{10}	85%	10% > 200
Rattler Run Nonpoint Sources		1.3 x10^{9}	1.2 x 10^{10}	89%	10% > 200
Fairfield WWTP		9.6 x10^{8}	3.0 x10^{9}	68%	NPDES permit
Hangman Creek at Keevy Road	45268	3.7 x10^{11}	1.7 x 10^{12}	78%	10% > 200
Hangman Creek at River Mile 21.4	45250	2.9 x10^{11}	6.7 x 10^{11}	56%	10% > 200
Rock Creek at Mouth	45312	6.6 x10^{10}	2.2 x 10^{11}	70%	10% > 200
Rock Creek at Jackson Road	41996	2.4 x10^{11}	7.5 x 10^{11}	68%	10% > 200
Rockford WWTP		2.8 x10^{8}	2.9 x10^{8}	3%	NPDES Permit
Freeman School District		1.3 x 10^{7}	2.0 x 10^{7}	15%	NPDES Permit
Rock Creek at Rockford	46317	2.4 x10^{10}	7.4 x 10^{10}	67%	10% > 200
Spangle Creek at Mouth	45347	8.6 x10^{8}	1.2 x 10^{9}	28%	10% > 200
Spangle Creek Nonpoint		8.4 x10^{8}	1.2 x 10^{9}	29%	10% > 200
Spangle WWTP		2.2 x 10^{7}	2.2 x 10^{7}	NPDES permit (no reduction)	
Hangman Creek at Duncan Road	45251	7.0 x10^{11}	7.8 x 10^{11}	10%	10% > 200
California Creek at Mouth	41991	2.5 x10^{9}	3.2 x 10^{9}	23%	10% > 200
California Creek at Marsh	46287	7.1 x10^{8}	1.4 x 10^{9}	49%	10% > 200
WA Dept. of Transportation		NC	NC	72%	10% > 200
Spokane(City & County) stormwater		NC	NC	72%	10% > 200
Marshall Creek at the Mouth	41995	8.3 x10^{8}	1.8 x 10^{9}	54%	10% > 200
Marshall Creek at McKenzie	46270	3.0 x 10^{9}	3.0 x 10^{9}	no reduction required	
Cheney WWTP*		1.6 x 10^{9}	1.6 x 10^{9}	NPDES permit (no reduction)*	
City of Spokane stormwater WLA		NC	NC	72%	10% > 200
Hangman Creek at Mouth	45260	2.3 x10^{10}	8.2 x 10^{10}	72%	10% > 200

* Cheney WWTP WLA based on effluent FC count to the wetland being the same if discharged to Minnie Creek.

The following conclusions and recommendations are based on this fecal coliform TMDL evaluation:

Conclusions

- Fecal coliform loads at the mouth of Hangman Creek appear to be decreasing over the long-term, but this may be a result of declining streamflows rather than declining FC counts.

- Fecal coliform counts exceed state criteria at several locations in the watershed, but no location appeared to be chronically degraded.
- Storm events at any time of the year result in elevated fecal coliform counts in many reaches of the watershed, and are the main cause of criteria violations that require TMDL load reductions.
- The sources of FC contamination in the watershed are not obvious, but may include livestock riparian access, malfunctioning on-site septic systems and WWTP disinfection systems, waterfowl and wildlife, and stormwater runoff.
- Disinfections practices at some WWTPs have improved over the past few years and now consistently comply with NPDES permit limits.
- Implementing a 72% FC load reduction at the mouth of Hangman Creek during the months of July through September should be adequate to reduce FC loads throughout the year.

Recommendations

- The mouth of Hangman Creek and reaches where informal swimming occurs should be the highest priority areas for FC abatement action.
- Ecology will need to work with the USEPA, Coeur d'Alene Tribe and Idaho to reduce FC loads in the upper Hangman Creek, Little Hangman Creek, and Rock Creek.
- Most sites require more intensive spatial and temporal monitoring to better identify sources of FC contamination.
- Phase 2 stormwater permit holders need to evaluate their systems and work with Ecology permit managers to ensure FC reductions are achieved.

Temperature

The temperature TMDL is built from work previously conducted for the Hangman Creek Watershed Planning Unit under the 2514 Watershed Planning process. Hardin-Davis (2003) used data collected by the Spokane County Conservation District (SCCD) for a Stream Network Temperature (SNTEMP) model. SNTEMP simulates mean daily temperatures along a stream under steady-state flow conditions (USGS, 2006). The model included 34.5 river miles from Hays Road to the mouth of Hangman Creek.

The SNTEMP modeling demonstrated that average temperatures could not meet criteria with small increases in flow (3 cfs) and an increase in shade from current conditions of 20% to 70% (Hardin-Davis, Inc., 2003). Additional work was necessary to provide TMDL shade targets.

The geographic information system (GIS) and modeling analysis was conducted using two specialized software tools:

- ODEQ's Ttools extension for Arcview (ODEQ, 2001) was used to sample and process GIS data for input to the Shade model.
- Ecology's Shade model (Ecology, 2003a) was used to estimate effective shade along the mainstems of Hangman Creek from the Idaho border to the mouth. Effective shade was calculated at 100-meter intervals along the streams and then averaged over 1000-meter intervals.

Tributaries were not analyzed directly from orthophotos and GIS tools. The tributaries and perennial streams in the Hangman Creek watershed are narrow enough that riparian vegetation shade would usually dominate stream cooling compared to geographic features. Shade curves and a shade table were created from the Shade model vegetation regional analysis. Shade potential for tributaries can be estimated when channel aspect and bankfull width are known.

The water quality standards require the stream in Hangman Creek to maintain a 7-day average maximum temperature of 17.5°C. If the average maximum temperature exceeds 17.5°C, the streams must maintain natural conditions. Natural conditions are determined by what the temperature of the water would be if mature riparian vegetation and microclimate conditions were present. This condition is referred to as the *system potential.*

The Hangman Creek mainstem model results for system potential shade compared to the current shade conditions are graphically displayed in Figure ES1. The average difference in current and system potential shade was 26% with the greatest need for additional shade in the upper 18 miles of the watershed and near the mouth.

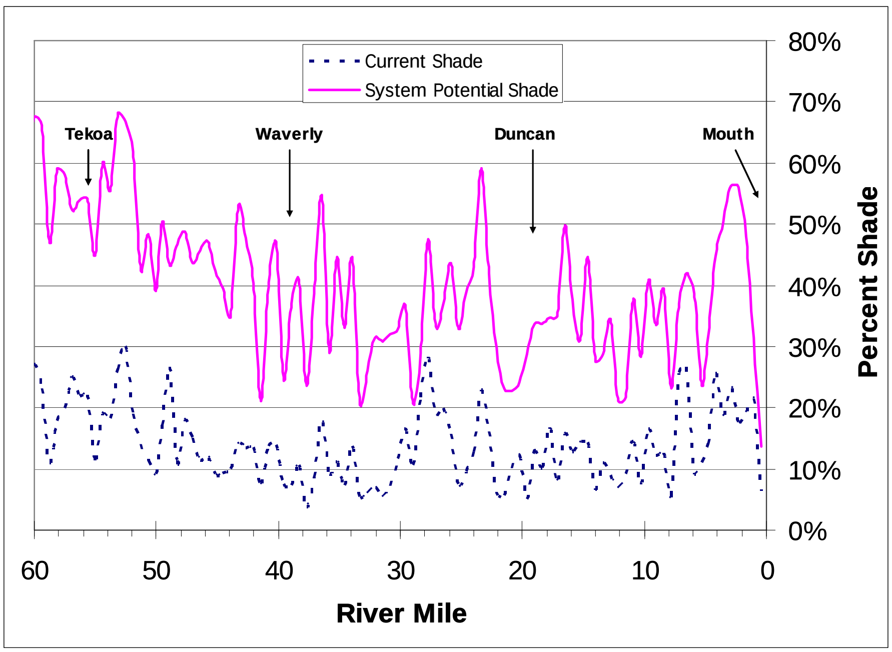


Figure ES1. Current conditions and system potential shade estimates (1000 meter averages) along Hangman Creek based on the shade model.

Table ES2 provides the heat load allocation and required vegetation shading terms for individual sites along Hangman Creek on the 2004 303(d) list and those proposed for the 2006/2008 303(d) list. Tributaries are also listed in the table. These were not directly modeled, so they require a different approach. The application of a shade curve based on the system potential shade used in the Shade model for the mainstem Hangman Creek is proposed as a load allocation mechanism.

Table ES2. Heat load allocations and shade requirements for 2004 and 2006/2008 303(d) listed sites in the Hangman Creek watershed based on the Shade model results. Heat is measured in watts per square meter (W/m^2). Tributary values need to have site specific metric collection and application of the shade curve in Figure ES3.

Water Body	Listing ID	Section, Township, Range	Location	W/m^2	Shade Required
Rattler Run	48303	Section 16 T22N R44E	Rattler Run at Mouth	Shade curve	Shade curve
Rock Creek	48333	Section 12 T23N R43E	Rock Creek Mouth	Shade curve	Shade curve
California Creek	48340	Section 03 T23N R43E	Calif. Creek mouth	Shade curve	Shade curve
Marshall Creek	48368	Section 31 T25N R43E	Marshall Cr. mouth	Shade curve	Shade curve
Hangman Creek	48370	Section 36 T25N R42E	River Mile 3.6	172	45%
Hangman Creek	48371	Section 31 T25N R43E	Above Marshall Cr.	212	32%
Hangman Creek	48372	Section 28 T24N R43E	HangmanValley Golf	225	28%
Hangman Creek	48373	Section 33 T24N R43E	River Mile 18.2	206	34%
Hangman Creek	48374	Section 11 T23N R43E	Duncan Road	207	34%
Hangman Creek	48375	Section 13 T23N R43E	Latah Road	181	42%
Hangman Creek	48376	Section 08 T22N R44E	Keevy Road	198	37%
Hangman Creek	48377	Section 16 T22N R44E	Bradshaw Road	247	21%
Hangman Creek	48378	Section 28 T22N R44E	Hays Road	222	29%
Hangman Creek	48379	Section 01 T21N R44E	Roberts Road	187	40%
Hangman Creek	48380	Section 30 T21N R45E	Spring Valley Road	165	47%
Hangman Creek	48381	Section 09 T20N R45E	Fairbanks Road	162	48%
Hangman Creek	48382	Section 24 T20N R45E	Above Tekoa WWTP	126	60%

Most tributary and perennial stream channels in the Hangman Creek watershed, including those in Table ES2, are narrow enough to be influenced more by vegetation shade than by landscape shade. As metrics are collected for sites in these areas, site potential effective shade can be assigned as a load allocation from Figure ES3 and the accompanying Table x, Appendix X.

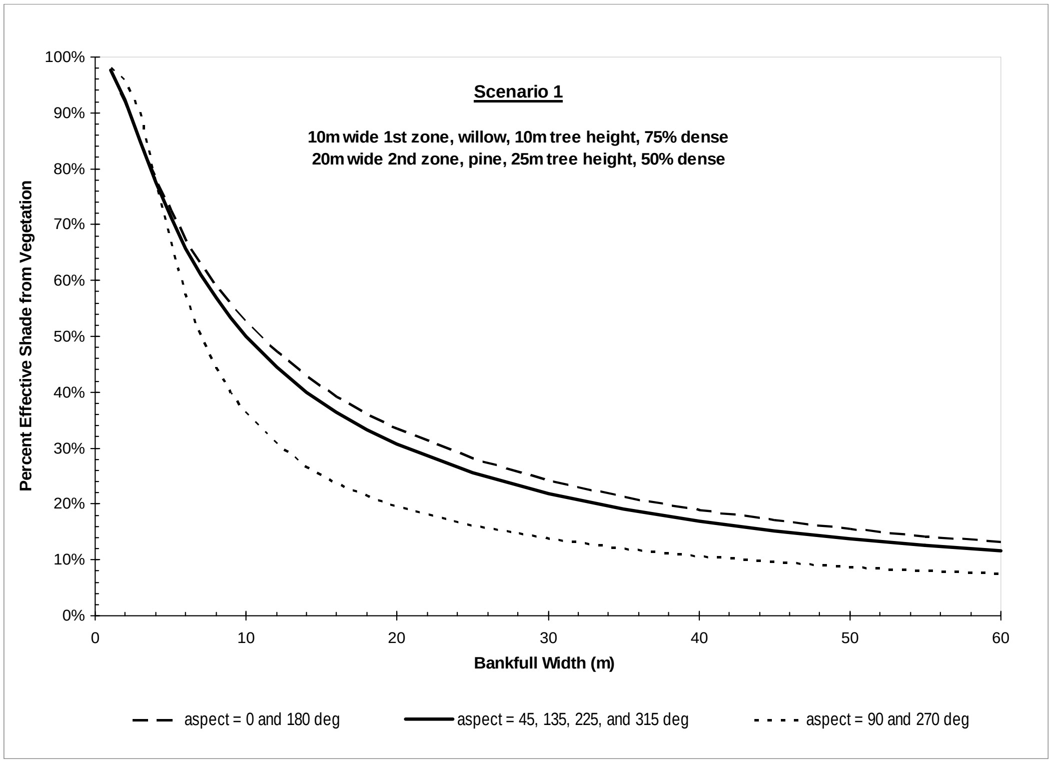


Figure ES3. Shade curve constructed for sites in the Hangman Creek watershed based on system potential vegetation maximum heights and stream orientation (aspect) to sunlight in August.

When the 7-day average daily maximum instream temperatures exceed 16.3 ºC, the allowable effluent temperature will be at the criteria temperature of 17.5 ºC for facilities at:

- Tekoa WWTP
- Fairfield,
- Spangle, and
- Freeman School District

The Cheney facility rarely discharges, but currently has a maximum summer temperature permit limit of 20 ºC and a mean of 14.2 ºC. These permit limits may be adequate if effluent does not increase the 7-day average daily maximum Minnie Creek temperatures above 17.5 ºC.

When the 7-day average daily maximum instream temperatures exceed 16.3 ºC, Rockford WWTP effluent can reach 18.25 ºC because the facility is only allowed to discharge when a dilution factor of 3.5 is available in Rock Creek.

The recommended effluent temperature limits will create some difficulties for some of the facilities in the Hangman Creek watershed. All of the WWTP facilities should monitor receiving water and effluent temperatures and discharge volumes during the spring through fall season. When the thermal and dilution cycles are better understood, compliance schedules and operational/facility options can be better designed.

The following conclusions and recommendations are based on this temperature TMDL evaluation:

- Many reaches of Hangman Creek and its tributaries cannot meet the 17.5ºC temperature criterion during the summer low-flow period.
- Groundwater and springs plays an important cooling role in the lower 10 miles of Hangman Creek below its confluence with Marshall Creek.
- A buffer of mature riparian vegetation along the banks of the creek and its tributaries is expected to decrease instream average daily maximum temperatures to natural levels.
- Site specific metrics of channel width and aspect will be necessary to apply the shade curve load allocations to tributaries and perennial streams.
- Channel restoration measures should be implemented to reduce heat loads on the stream and encourage riparian vegetation growth.

Total Phosphorus

Hangman Creek total phosphorus loads of greatest concern to the Spokane River are generated in the spring; summer loads are minor additions. The Spokane River Dissolved Oxygen TMDL has recommended load allocations to Hangman Creek for the months of *April through October.* The months of *April, May and June are the most critical* in terms of phosphorus discharge from Hangman Creek affecting the Spokane River.

The spring phosphorus loads are generated by relatively short duration events. Hangman Creek has a very ‘flashy’ hydrograph during the spring. The flashiness is an important characteristic that influences sediment and phosphorus transport from the watershed and along the stream channel. Hangman Creek’s April to June TP loads are the highest for the Spokane River and Lake Spokane. However, phosphorus loads generated by sources in the watershed do not necessarily reach the Spokane River immediately. Phosphorus generated in upper Hangman Creek in Idaho may take years to reach the Spokane River because of long periods of settling in intervening channels until a scour event of high enough intensity and duration can move it downstream.

Several tools were used to determine the load capacity of Hangman Creek and compare the relative contributions of various sources. The Hangman Creek Advisory Committee questioned if the TP load capacity should be predicted from a pristine or natural state scenario. The following points were made:

- the channel and land use had changed greatly over the past centuries of human habitation
- no reference sub-watersheds were available for each of the diverse Ecoregions represented in the watershed

Therefore, the best potential or future reference condition for the watershed was based on a question put to the Hangman Creek Advisory Committee:

“What is the best possible set of actions that could be implemented in the Hangman Creek watershed to achieve phosphorus reductions?”

The recommendations by the Advisory Committee covered a wide range of progressive actions:

- Convert 60% of the agriculture in the watershed to direct seed or conservation practices.
- Have 10 foot riparian buffers established all along the mainstem channels and tributaries.
- Reduce the streambank erosion in the upper watershed (above Fairfield) by 50% and erosion in the lower watershed with Lake Missoula flood sediments by 10%.
- Increase forest cover in catchments above Rockford and Tensed by 50%.
- Limit residential growth to levels below 10% in lower watershed (catchments 3, 4, 7, 9 and 10).
- Eliminate point source discharges to surface water.
- Repair failing residential on-site septic systems.

The calibrated WARMF model was used to estimate the effect of this set of best management practices (BMPs) to reduce phosphorus in Hangman Creek In summary, the total phosphorus load and wasteload allocations recommended for the Hangman Creek can be summarized based on this TMDL analysis (Table ES3). The allocations are based on the best potential BMPs and point source reductions in sub-watersheds. The cumulative transport from upstream sources is considered in the allocations at points along the Hangman Creek mainstem, and within tributaries.

Table ES3. A summary of current total phosphorus (TP) loads, and recommended load and waste load allocations (WLA) for sub-watersheds and point sources in Hangman Creek. Analyses are based on long-term daily average loads over a period of seven water years with a variety of flow regimes.

Hangman Creek Sub-watershed or Point Source	Current Load lbs TP/day (kg TP/day)	WLA or Load Allocation lbs TP/day (kg TP/day)	Target Reduction (%)
Hangman Creek at State Line	22 (10)	16 (7.3)*	26%
Tensed WWTP	2.7 (1.2)	0.04 (0.02)*[+]	98%
Hangman Creek from Tekoa to Bradshaw Road & Little Hangman	47 (21)	36 (16)	23%
Little Hangman at State Line	15 (6.8)	13 (6.1)*	10%
Tekoa WWTP	5.7 (2.6)	0.11 (0.05)[+]	98%
Hangman Creek from Bradshaw to Duncan Road and Gage	61 (28)	47 (21)	23%
Fairfield WWTP	1.7 (0.76)	0.03 (0.01)[+]	98%
Spangle	0.32 (0.15)	0.004 (0.002)[+]	98%
Rock Creek at Mouth	15 (6.8)	13 (5.9)	14%
Rockford WWTP	0.98 (0.44)	0.02 (0.009)[+]	98%
Freeman School District WWTP	0.002 (0.001)	0.002 (0.001)	-
Rock Creek at State Line	12 (5.6)	11 (5.0)*	10%
Marshall Creek at the Mouth	5.7 (2.6)	5.7 (2.6)	1%
Cheney WWTP	0.004 (0.002)	0.004 (0.002)	-
Spokane(City & County) stormwater	0.28 (0.13)	0.28 (0.13)	-
Hangman Creek at Mouth	101 (46)	78 (36)	20%

City of Spokane, County, and WA Dept. of Transportation stormwater	3.2 (1.5)	3.2 (1.4)	-

* Allocations and WLA for areas outside of the State of Washington jurisdiction are shown for demonstration purposes.

+ Estimate based on total phosphorus effluent concentration of 0.05 mg/L (50 µg/L).

The following conclusions and recommendations are based on this total phosphorus TMDL evaluation:

- Total P and orthophosphate phosphorus (OPO_4-P) concentrations at the mouth of Hangman Creek have declining trends over the past 10 years (1995 – 2005). However, streamflows have dropped over the same period.
- Phosphorus concentrations are significantly correlated with streamflow and sediment concentrations in Hangman Creek.
- Approximately 35% of the land area of Hangman Creek lies within the Coeur d'Alene Reservation and Idaho, and 60% of the average annual streamflow comes from there.
- Total phosphorus loads from Hangman Creek are of greatest concern to Spokane River/Lake Spokane water quality in the months of April, May, and June. Streambank and upland erosion from agricultural lands during storm and snowmelt events are major sources at that time.
- The estimated load capacity for Hangman Creek in April and May is less than the recommended Spokane River/Lake Spokane TMDL load allocations. Spokane River model adjustments to higher TP natural conditions may bring the two estimates into better agreement.
- Point sources in the Hangman Creek watershed deliver significant TP loads, especially during the low-flow months.
- Model results confirm that phosphorus generated in upper Hangman Creek and in Idaho may take years to reach the Spokane River because of long periods of settling in intervening channels until a scour event of high enough intensity and duration can move it downstream. Some phosphorus also is taken-up into the aquatic community as plant and animal life with varying life spans.
- Day to day TP concentration and streamflow variability will be a problem for compliance assessment. The sudden onset of storm and run-off events can radically change monthly and seasonal average loads depending on whether or not they are part of the sample set.
- Future model development will require additional data:
    - Precipitation data from several areas within the watershed.
    - Continuous streamflow and routine phosphorus monitoring at major tributaries and points along the mainstem.
    - Better phosphorus and effluent discharge data from WWTPs and stormwater point sources
    - Soil-water phosphorus concentrations from various ecoregions in the watershed.
    - Rates, spatial and seasonal distribution, and biomass estimates of aquatic macrophytes and periphyton within the watershed.
    - Erosion rates from streambank and upland areas of the watershed.

- The number of systems and rates of on-site septic failure in various sub-watersheds.
- Data on the soluble phosphorus fraction of the total phosphorus load at various sites in the watershed.

- Spokane River and Lake Spokane dissolved oxygen responses to Hangman Creek TP loads under higher streamflow conditions have not been evaluated, but may be necessary to fine-tune the Hangman Creek allocations. In the meantime, the April – May seasonal load allocation for Hangman Creek under low-flow conditions should be re-evaluated in cooperation with the Spokane River and Lake Spokane DO TMDL work using the CE-QUAL-W2 model.
- Many implementation measures for this and the other TMDLs in the watershed will help to reduce TP, and help reduce DO and pH criteria violations.

Turbidity and Total Suspended Solids

To be completed 2/12

Table SS4. Suspended sediment reduction predicted from WARMF model scenario estimates for annual suspended sediment loading from Hangman Creek to the Spokane River. WARMF model current and best potential scenario condition results were compared. The percent reduction in suspended sediment loading is applied to the regression model estimates in Table SS4 to provide an estimate of the annual load capacity.

Water Year	Multiple Regression Model (tons/year)	Estimated Reduction	Estimated Load Capacity (tons/year)
1999	188,252	22%	147,206
2000	90,677	25%	67,872
2001	1,604	31%	1,109
2002	73,770	28%	53,326
2003	16,503	21%	13,101
2004	30,605	32%	20,846
2005	2,832	29%	2,022

Table SS5. Estimated distribution of sources generating suspended sediment in sub-watersheds of Hangman Creek under current and best potential condition scenarios and estimated source reduction expected with implementation of best potential scenario actions

Sub-Watershed	**Current % of sources**	**Best Potential % of sources**	**Estimated source Reduction**	**Land Area % of watershed**
Upper Hangman	35%	32%	26%	20%
Little Hangman & Hangman from Tekoa to Bradshaw	26%	27%	16%	19%
Hangman from Bradshaw to Duncan & Rattler Run	1%	1%	15%	8%
Rock Creek	20%	20%	18%	27%
Marshall Creek	2%	3%	8%	11%
Lower Hangman	16%	17%	11%	15%

Table SS6. WARMF model simulation results for overall suspended sediment reductions and source reductions estimated at 303(d) sites in the Hangman Creek watershed.

Site	**Overall Reduction**	**Primary Sources**	**Reduction to Sources**
Hangman Creek at Bradshaw Rd	19%	Conventional Agriculture. Streambanks Rangelands	56% 74% 31%
Little Hangman Creek	15%	Conventional Agriculture	55%
Rattler Run Creek	15%	Conventional Agriculture	54%
Rock Creek	17%	Conventional Agriculture Rangelands Streambanks	55% 18% 90%

Implementation Strategy

This Implementation Strategy describes the roles and authorities of cleanup partners and the programs and provides strategy to achieve the water quality standards for fecal coliform bacteria, turbidity, temperature, and nutrients (total phosphorus). The development of this plan was a collaborative effort by a diverse group of interests in the watershed.

Implementation activities will generally involve the Spokane County Conservation District, Washington Department of Ecology, Spokane County, the City of Spokane, the 6 wastewater treatment plants, the Coeur d' Alene Tribe and the Environmental Protection Agency. Implementation will be jointly facilitated and tracked by the Spokane Conservation District and the Department of Ecology. These agencies will also involve other agencies and groups, such as the Spokane Regional Health District, the Direct Seed Association, Washington State University Extension, seed and fertilizer companies, local producer based cooperatives, the Natural Resources Conservation Service, and the Farm Service Agency.

After the U.S. Environmental Protection Agency (EPA) approves this TMDL, interested and responsible parties will work together to develop a *Water Quality Implementation Plan*. The plan will describe and prioritize specific actions planned to improve water quality and achieve water quality standards.

A Hangman Creek Advisory Committee was formed in April 2004. In addition to the point sources in the watershed, the committee identified 11 water quality nonpoint issues that were potential sources of the water quality problems in the watershed:

Issue 1: Sediment/nutrients from agricultural operations
Issue 2: Sediment/fecal coliform from livestock and wildlife
Issue 3: Nutrients/chemicals from residential uses
Issue 4: Sediment/nutrients from agricultural field ditches
Issue 5: Nutrients/fecal coliform from improper functioning septic systems
Issue 6: Sediment from gravel and summer roads
Issue 7: Sediment from sheer or undercut banks
Issue 8: Sediment/fecal coliform from stormwater
Issue 9: Sediment from poor forestry management

Issue 10: Sediment from roadside ditching
Issue 11: Solar heating from lack of riparian shade.

The six wastewater treatment facilities and the three stormwater jurisdictions covered by stormwater permits were assigned wasteload allocations in this TMDL to ensure they do not contribute to water quality standards violations. These wasteload allocations will be implemented through their National Pollutant Discharge Elimination System (NPDES) permits.

To address the nonpoint sources, the advisory committee developed a list of best management practices to address each of the nonpoint source water quality issues identified. Stormwater is included because much of the watershed is not covered under a stormwater permit. Many of the BMPs address more than one of the water quality issues. To address the water quality parameters addressed by this TMDL, pollution reductions will be accomplished through best management practices that:

- Reduce erosion.
- Reduce runoff carrying sediment.
- Reduce livestock impacts.
- Increase shading of streams.
- Inform and educate watershed residents about water quality issues.

Education, outreach, technical and financial assistance, permit administration, and enforcement will all be used to ensure that the goals of this water improvement plan are met. There are many sources of funding and technical assistance to facilitate implementing this TMDL.

Once EPA approves the TMDL, a *Water Quality Implementation Plan* (WQIP) must be developed within one year. Ecology and the SCCD will work with local people to create this plan, choosing the combination of possible solutions they think will be most effective in their watershed. Elements of this plan include:

- Who will commit to do what.
- How to determine if the implementation plan works.
- What to do if the implementation plan doesn’t work.
- Potential funding sources.

In developing the WQIP, Ecology and the SCCD will ensure the plan addresses the recommendations made in this report.

What is a Total Maximum Daily Load (TMDL)?

Federal Clean Water Act requirements

The Clean Water Act established a process to identify and clean up polluted waters. Under the Clean Water Act, each state is required to have water quality standards designed to protect, restore, and preserve water quality. Water quality standards are set to protect designated uses such as cold water biota and drinking water supply.

Every two years, states are required to prepare a list of waterbodies - lakes, rivers, streams, or marine waters - that do not meet water quality standards. This list is called the 303(d) list. To develop the list, Ecology compiles its own water quality data along with data submitted by local state and federal governments, tribes, industries, and citizen monitoring groups. All data are reviewed to ensure that they were collected using appropriate scientific methods before they are used to develop the 303(d) list.

TMDL process overview

The Clean Water Act requires that a Total Maximum Daily Load or TMDL be developed for each of the waterbodies on the 303(d) list. A TMDL identifies how much pollution needs to be reduced or eliminated to achieve clean water. Then Ecology, local governments, agencies and the community develop a strategy to control the pollution, and a monitoring plan to assess effectiveness of the water quality improvement activities.

Elements required in a TMDL

The goal of a TMDL is to ensure the impaired water will attain water quality standards. A TMDL includes a written, quantitative assessment of water quality problems and of the pollutant sources that cause the problem. The TMDL determines the amount of a given pollutant that can be discharged to the waterbody and still meet standards (the loading capacity) and allocates that load among the various sources.

If the pollutant comes from a discrete source (referred to as a point source) such as a municipal or industrial facility’s discharge pipe, that facility’s share of the loading capacity is called a wasteload allocation. If it comes from a set of diffuse sources (referred to as a nonpoint source) such as general urban, residential, or farm runoff, the cumulative share is called a load allocation.

The TMDL must also consider seasonal variations and include a margin of safety that takes into account any lack of knowledge about the causes of the water quality problem or its loading capacity. A reserve capacity for future loads from growth pressures is sometimes included as well. The sum of the wasteload and load allocations, the margin of safety and any reserve capacity must be equal to or less than the loading capacity.

Water quality assessment / Categories 1-5

The Water Quality Assessment categorizes waterbodies based on water quality data. This assessment gives an indication of the condition of Washington's water. The 303(d) list is one of the categories within the assessment. The five categories are:

- Category 1 – Meets standards for parameter(s) for which it has been tested.
- Category 2 – Waters of concern.
- Category 3 – Waters with no data available.
- Category 4 – Polluted waters that do not require a TMDL because:
    - 4a – Has a TMDL approved and its being implemented
    - 4b – Has a pollution control plan in place that should solve the problem
    - 4c – Impaired by a non-pollutant such as low water flow, dams, culverts
- Category 5 – Polluted waters that require a TMDL – or the 303d list.

Total Maximum Daily Load analyses: Loading capacity

Identification of the contaminant loading capacity for a waterbody is an important step in developing a TMDL. EPA defines the loading capacity as "the greatest amount of loading that a waterbody can receive without violating water quality standards" (USEPA, 2001). The loading capacity provides a reference for calculating the amount of pollution reduction needed to bring a waterbody into compliance with standards. The portion of the receiving water's loading capacity assigned to a particular source is a load or wasteload allocation. By definition, a TMDL is the sum of the allocations, which must not exceed the loading capacity.

Why is Ecology Conducting a TMDL Study in this Watershed?

Overview

Ecology and the Spokane County Conservation District (SCCD) are conducting a TMDL study because Hangman Creek was identified on the 1998 303(d) list of impaired waters for not meeting state water quality standards for fecal coliform, dissolved oxygen, pH, and temperature. Hangman Creek and several of its tributaries (Little Hangman Creek, Rattler Run Creek, and Rock Creek) were also included on the 2004 303(d) list of impaired water for not achieving state water quality standards for fecal coliform, dissolved oxygen, turbidity, and temperature. Recent monitoring by The SCCD and Ecology has identified several other water quality problems not included on either list of impaired waters (sediment load, low flows, and total phosphorus). Streams are not listed on the 303(d) list for these parameters because the water quality standards do not set criteria for them. Issues such as storm-water runoff, sedimentation, riparian vegetation losses, stream bank erosion, wetland losses, and agricultural and forestry management are major concerns for the watershed.

Study area

Hangman Creek (also known as Latah Creek) is a trans-boundary watershed that begins in the foothills of the Rocky Mountains of northern Idaho, extends over the southeastern portion of Spokane County, Washington (Figure 1), and is a tributary to the Spokane River. It encompasses over 689 square miles (approximately 430,000 acres). The watershed is dominated by dryland farming, but like other eastern Washington watersheds, is experiencing increases in urbanization and changes in land use practices.

The TMDL evaluation is limited to the 446 square miles of watershed within Washington, although landscape modeling was conducted on the entire watershed. Rock Creek and Little Hangman Creek trans-boundary watersheds within Washington are included in this evaluation. The Coeur d'Alene Tribe is conducting a TMDL study and the State of Idaho has completed a TMDL for the portions of the watershed within their jurisdictions.

Pollutants addressed by this TMDL

This TMDL study addresses phosphorus, fecal coliform bacteria, temperature, and turbidity. In addition to developing TMDLs specific to the Hangman Creek watershed, a phosphorus load allocation has been recommended for Hangman Creek by the Spokane River/Lake Spokane Dissolved Oxygen TMDL study. The Spokane River and Lake Spokane exhibit depressed dissolved oxygen (DO) levels during low flow in the summer months. Phosphorus loads from

Hangman Creek and other sources in the Spokane River basin contribute to algae growth in the lake that eventually depress oxygen levels.

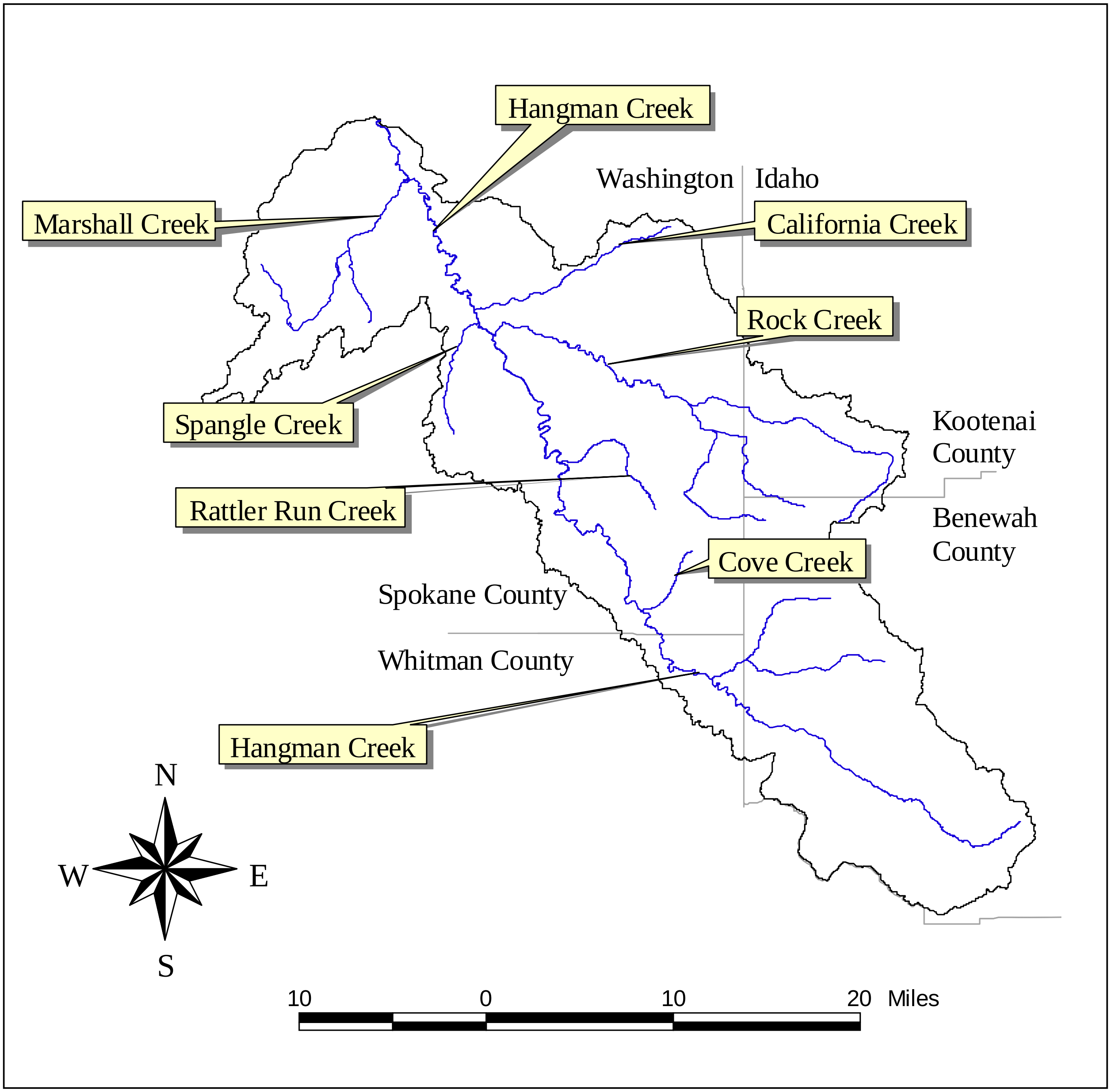


Figure 1. Hangman Creek Watershed Location Map

Impaired beneficial uses and waterbodies on Ecology's 303(d) list of impaired waters

The main beneficial uses to be protected by this TMDL are recreation and aquatic habitat. The specific waterbodies, parameters, listing ID, and locations from Ecology's 2004 303(d) list are in Table 1. The work performed for this TMDL evaluation also identified additional waterbodies that qualify for the proposed 2006/2008 303(d) list (Table 2). Both sets of lists will be addressed and receive allocations in this TMDL report.

Table 1. Study area 303(d) listings (2004 list) addressed in this report.

Waterbody	Parameter	Listing ID	Section, Township, Range
Hangman Creek	Fecal Coliform	16862	Section 23 T25N R42E
Hangman Creek	Fecal Coliform	16863	Section 16 T22N R44E
Hangman Creek	Fecal Coliform	6726	Section 13 T20N R45E
Hangman Creek	Fecal Coliform	41992	Section 25 T20N R46E
Hangman Creek	Turbidity	40942	Section 16 T22N R44E
Little Hangman Creek	Fecal Coliform	41994	Section 24 T20N R45E
Little Hangman Creek	Turbidity	40940	Section 13 T20N R45E
Rattler Run Creek	Turbidity	40941	Section 16 T22N R44E
Rock Creek	Fecal Coliform	41996	Section 23 T23N R44E
Hangman Creek	Temperature	3736	Section 23 T25N R42E
Rock Creek	Turbidity	40943	Section 23 T23N R44E

This watershed has other water quality issues that will not be addressed in this TMDL. In particular, the parameters listed in Table 3 occur in the study area, but are not addressed in this report. It is believed that the implementation activities outlined in this TMDL will also benefit these parameters. Un-ionized ammonia concentrations were incorrectly calculated for the 2004 list and the data from these sites do not exhibit ammonia toxicity above aquatic life criteria. Ammonia listings in Table 3 are probably errors.

The phosphorus load allocation for Hangman Creek proposed by the Spokane River TMDL is a focus of this TMDL as well. Sources of phosphorus loading within the watershed have been analyzed and reductions are proposed. These may not necessarily be restrictive enough to prevent nutrient eutrophication problems within the Hangman Creek watershed. Some of the pH and dissolved oxygen (DO) listings for the watershed in Table 3 may be caused by excessive phosphorus. Resources were not available to investigate fully the interaction between nutrients, pH and DO.

Table 2. Additional impairments on the proposed 2006/2008 303(d) list which will receive allocations in this TMDL. Most of these listings resulted from data collected for this study.

Waterbody	Parameter	Listing ID	Section, Township, Range
Hangman Creek	Fecal Coliform	45242	Section 01 T21N R44E
Hangman Creek	Fecal Coliform	45250	Section 13 T23N R43E
Hangman Creek	Fecal Coliform	45268	Section 08 T22N R44E
Rattler Run Creek	Fecal Coliform	45310	Section 16 T22N R44E
Rock Creek	Fecal Coliform	45312	Section 12 T23N R43E
Unnamed Creek	Fecal Coliform	45553	Section 13 T21N R44E
Cove Creek	Fecal Coliform	45629	Section 30 T21N R45E
California Creek	Fecal Coliform	46287	Section 18 T24N R45E
Rock Creek	Fecal Coliform	46317	Section 33 T23N R45E
Hangman Creek	Fecal Coliform	46493	Section 30 T21N R45E
Hangman Creek	Fecal Coliform	46497	Section 09 T20N R45E
Rattler Run	Temperature	48303	Section 16 T22N R44E
Rock Creek	Temperature	48333	Section 12 T23N R43E
California Creek	Temperature	48340	Section 03 T23N R43E
Marshall Creek	Temperature	48368	Section 31 T25N R43E
Hangman Creek	Temperature	48370	Section 36 T25N R42E
Hangman Creek	Temperature	48371	Section 31 T25N R43E
Hangman Creek	Temperature	48372	Section 28 T24N R43E
Hangman Creek	Temperature	48373	Section 33 T24N R43E
Hangman Creek	Temperature	48374	Section 11 T23N R43E
Hangman Creek	Temperature	48375	Section 13 T23N R43E
Hangman Creek	Temperature	48376	Section 08 T22N R44E
Hangman Creek	Temperature	48377	Section 16 T22N R44E
Hangman Creek	Temperature	48378	Section 28 T22N R44E
Hangman Creek	Temperature	48379	Section 01 T21N R44E
Hangman Creek	Temperature	48380	Section 30 T21N R45E
Hangman Creek	Temperature	48381	Section 09 T20N R45E
Hangman Creek	Temperature	48382	Section 24 T20N R45E

Table 3. Additional 303(d) listings not addressed by this report.

Waterbody	Parameter	Listing ID	Section, Township, Range
Hangman Creek	Dissolved Oxygen	41985	Section 29 T20N R46E
Hangman Creek	Dissolved Oxygen	41987	Section 16 T22N R44E
Hangman Creek	pH	11391	Section 23 T25N R42E
Rock Creek	Dissolved Oxygen	41990	Section 23 T23N R44E
Hangman Creek	Ammonia*	41977	Section 29 T20N R46E
Hangman Creek	Ammonia*	41978	Section 16 T22N R44E
Little Hangman Creek	Ammonia*	41979	Section 24 T20N R45E

* Preliminary review of the data suggests the ammonia criteria were not applied correctly and these listings should be dropped from the list.

Why are we doing this TMDL now?

Ecology examines each watershed every five years to determine if there are impaired streams which need a TMDL to restore water quality. In 2003, Ecology considered impaired streams in the Hangman Creek, Little Spokane River, Middle Spokane, and Lower Spokane watersheds. Because a TMDL was underway for the Spokane River which would set allocations at the mouths of Hangman Creek and the Little Spokane River, these watersheds were scheduled for TMDL development. Completing this TMDL now provides an area-wide approach to phosphorus reduction needed for water quality concerns identified in the Spokane River/Lake Spokane TMDL.

Water Quality Standards and Beneficial Uses

The Washington State Water Quality Standards are published pursuant to Chapter 90.48 of the Revised Code of Washington (RCW). The state Department of Ecology has the authority to adopt rules, regulations, and standards necessary to protect the environment. The EPA Regional Administrator under Section 303(c) (3) of the federal Clean Water Act approves the state water quality standards adopted by Ecology. By adopting these standards, Washington lists characteristic uses to be protected and the criteria used to protect them (WAC 173-201A).

Hangman Creek and its tributaries have not been given any specific use designations in the water quality standards. Core summer salmonid (salmon, trout and related species) habitat, national parks, national forests, and wilderness areas are not present in the Washington portion of the watershed. The standards include the following general use designation for such waters:

> **173-201A-600**
> **Use designations — Fresh waters.**
> (1) All surface waters of the state not named in Table 602 are to be protected for the designated uses of: Salmonid spawning rearing, and migration; primary contact recreation; domestic, industrial, and agricultural water supply; stock watering; wildlife habitat; harvesting; commerce and navigation; boating; and aesthetic values.

Some water quality problems are a result of natural conditions, or do not have specific state or federal criteria and standards. In this TMDL these include temperature, totals suspended solids (a surrogate parameter for turbidity) and phosphorus (required to meet downstream dissolved oxygen limits). The following portions of the water quality standards apply to these water quality problems requiring natural condition assessment or lacking specific criteria:

> **173-201A-260**
> **Natural conditions and other water quality criteria and applications**
>
> (1) **Natural and irreversible human conditions**
> *(a) It is recognized that portions of many water bodies cannot meet the assigned criteria due to the natural conditions of the water body. When a water body does not meet its assigned criteria due to natural climatic or landscape attributes, the natural conditions constitute the water quality criteria.*
> *(b) When a water body does not meet its assigned criteria due to human structural changes that cannot be effectively remedied (as determined consistent with the federal regulations at 40 CFR 131.10), then alternative estimates of the attainable water quality conditions, plus any further allowances for human effects specified in this chapter for when natural conditions exceed the criteria, may be used to establish an alternative criteria for the water body…*

(2) **Toxic and aesthetics criteria**
(a) Toxic, radioactive, or deleterious material concentrations must be below those which have potential, either singularly or cumulatively, to adversely affect characteristic water uses, cause acute or chronic conditions to the most sensitive biota dependent upon those waters, or adversely affect public health…
(b) Aesthetic values must not be impaired by the presence of materials or their effects, excluding those of natural origin, which offend the senses of sight, smell, touch, or taste…

173-201A-310
Tier I – Protection and maintenance of existing and designated uses.
(1) Existing and designated uses must be maintained and protected. No degradation may be allowed that would interfere with, or become injurious to, existing or designated uses, except as provided in this chapter.

(2) For waters that do not meet assigned criteria, or protect existing or designated uses, the department will take appropriate and definitive steps to bring the water quality back into compliance with the water quality standards.

(3) Whenever the natural conditions of a water body are of lower quality than the assigned criteria, the natural condition constitutes the water quality criteria. Where water quality criteria are not met because of natural conditions, human actions are not allowed to further lower the water quality, except where explicitly allowed in this chapter.

Recreational contact uses

Neither Hangman Creek nor its tributaries in Washington have designated swimming areas, but informal swimming has been observed by SCCD field personnel at several locations near bridge crossings (for example at Hangman Creek at Duncan Road). Swimming is a listed amenity by the City of Spokane at High Bridge Park at the mouth of Hangman Creek. Canoeing, kayaking, fishing, and wading are seasonal activities in the Hangman Creek watershed. Several kayaking websites describe water quality challenges kayakers face in Hangman Creek.

Fecal Coliform Bacteria

Bacteria criteria are set to protect people who work and play in and on the water from waterborne illnesses. In the Washington State water quality standards, fecal coliform is used as an "indicator bacteria" for the state's freshwaters (e.g., lakes and streams). Fecal coliform in water indicate the presence of waste from humans and other warm-blooded animals. Waste from warm-blooded animals is more likely to contain pathogens that will cause illness in humans than waste from cold-blooded animals. The fecal coliform criteria are set at levels that have been shown to maintain low rates of serious intestinal illness (gastroenteritis) in people.

Coliform bacteria have been used as indicators of fecal contamination since the 1880s (Geldrich, 1966). Coliforms are a group of bacteria with certain shapes that produce gas from sugars and respond to other tests in specific ways. Different sub-sets of the coliform group are used as indicators for specific regulatory purposes. Figure 2 illustrates how the sub-sets within the coliform group are related.

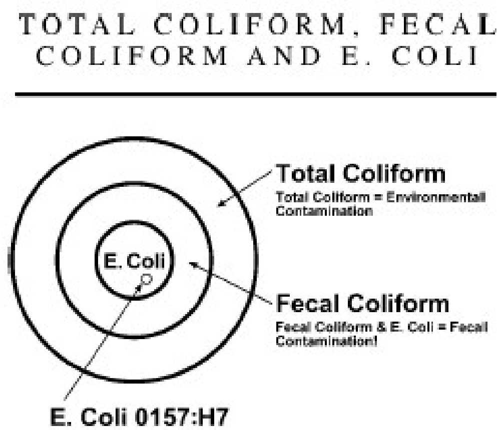


Figure 2. Relationship between Total Coliform, Fecal Coliform, and E. Coli (Washington State Department of Health, 2005).

Total coliforms are used as indicators of general environmental contamination, and as a regulatory indicator for reclaimed wastewater disposal. For example, the seven-day median concentration of total coliforms cannot exceed 2.2 per 100 milliliters in Class A reclaimed water for use on crops (Washington State Department of Health, 1997).

Fecal coliform bacteria are used as indicators of the presence of other pathogenic enteric organisms. When FC are found in large numbers, it means that fecal wastes are entering waterways and creating a greater potential for infection from pathogens when people come in contact with these waters. State water quality standards do not distinguish between human and other sources of FC since disease organisms that affect humans are carried in fecal wastes from other warm-blooded animals as well.

Bacteria from the genera *Escherichia, Citrobacter, Klebsiella, Enterobacter*, and *Serratia* (among others) are detected in the FC analysis (APHA et al., 1998). All are present in the feces of warm-blooded animals, but some species may be from other sources as well. Usually, *Escherichia coli* (E. coli) are the dominant species detected in the FC test. Samples with a large number of E. coli would more likely come from a warm-blooded animal source than samples with a high percentage of thermo-tolerant *Klebsiella* species that can be found in pulp waste or rotting vegetation.

The *Primary Contact* use is intended for waters "where a person would have direct contact with water to the point of complete submergence including, but not limited to, skin diving, swimming, and waterskiing." More to the point, however, the use is designated to any waters where human exposure is likely to include exposure of the eyes, ears, nose, and throat. Since children are also the most sensitive group for many of the waterborne pathogens of concern, even shallow waters may warrant primary contact protection. To protect this use category:

> "Fecal coliform organism levels must not exceed a geometric mean value of 100 colonies/100 mL, with not more than 10 percent of all samples (or any single sample when less than ten sample points exist) obtained for calculating the geometric mean value exceeding 200/colonies mL" [WAC 173-201A-200(2)(b), 2003 edition].

Compliance is based on meeting both the geometric mean criterion and the 10% of samples (or single sample if less than ten total samples) limit. These two measures used in combination ensure that bacterial pollution in a waterbody will be maintained at levels that will not cause a greater risk to human health than intended. While some discretion exists for selecting sample averaging periods, compliance will be evaluated for both monthly (if five or more samples exist) and seasonal (summer versus winter) data sets.

The criteria for fecal coliform are based on allowing no more than the pre-determined risk of illness to humans that work or recreate in a waterbody. The criteria used in the state standards are designed to allow seven or fewer illnesses out of every 1,000 people engaged in primary contact activities. Once the concentration of fecal coliform in the water reaches the numeric criterion, human activities that would increase the concentration above the criteria are not allowed. If the criterion is exceeded, the state will require that human activities be conducted in a manner that will bring fecal coliform concentrations back into compliance with the standard.

If natural levels of fecal coliform (from wildlife) cause criteria to be exceeded, no allowance exists for human sources to measurably increase bacterial pollution. While the specific level of illness rates caused by animal versus human sources has not been quantitatively determined, warm-blooded animals (particularly those that are managed by humans and thus exposed to human derived pathogens as well as those of animal origin) are a common source of serious waterborne illness for humans.

Aquatic life uses

Hangman Creek has no specific aquatic use designations either, so the assigned aquatic life criteria are required to protect salmonid spawning, rearing and migration (WAC 173-201A-600(1)) as stated earlier. These criteria are appropriate considering the Hardin-Davis, Inc. (2003) report provided the following summary of historical and current fish stocks in Hangman (Latah) Creek:

"Historically, Latah Creek [Hangman] *supported salmon and steelhead runs in the mainstem all the way to the headwaters. Anadromous fish were blocked by the construction of Little Falls Dam in 1910. Resident trout still occur in Latah Creek, but the numbers and distribution are sparse (Edelen & Allen 1998). Low summer flows and high temperatures are thought to be the main limiting factors to salmonid populations today. At present, the Latah Creek fishery is dominated by minnows (Cyprinidae) and suckers (Catostomidae). Based on recent collections,*

at least 12 species occur in Latah Creek (Edelen and Allen 1998; Laumeyer and Maughan 1973, 1974); 3 of these are introduced…"

A more recent macroinvertebrate survey conducted by Ecology in 2003 also provides some insight into the health of the Hangman Creek aquatic communities. Ecology (2005) summarized the survey results from three mainstem and four tributary sites as follows:

- California Creek and Marshall Creek had relatively high metric scores (healthier benthic communities)
  - Significantly higher clinger functional group species; higher percentages of ephemeroptera, plecoptera, and tricoptera (EPT) and long-lived species; and higher total richness scores
  - Presence of intolerant or moderately tolerant taxa
- The mainstem sites had relatively low metric scores (less healthy benthic communities):
  - Presence of more tolerant taxa
  - An unusual set of assemblages for a small stream
  - An assemblage of mayflies that are more common in a large open stream or river

Several water quality standards and criteria are designed to protect aquatic communities and their habitat from harm. Criteria are set to protect beneficial uses to fish, shellfish and crustacean for migration, spawning, and rearing. Wildlife habitat is another beneficial use protected in the standards. Turbidity, temperature, and nutrients are three pollutants of concern in the Hangman Creek watershed that can have deleterious effects on aquatic communities.

Turbidity

Turbidity is a measure of light refraction in the water and is used to control the amount of sediment and suspended solids. Turbidity is measured in nephelometric turbidity units (NTU). Fish and other aquatic life are affected by suspended solids in the water column and sediment that has settled out on the bottom of the waterbody. The effects of suspended sediment and solids on fish and other aquatic life can be divided into four categories: (1) acting directly on the fish swimming in the water and either killing them or reducing their growth rate, resistance to disease, etc.; (2) preventing the successful development of fish eggs and larvae; (3) modifying behavior, natural movements and migrations; (4) reducing the abundance of available food.

Suspended sediment and solids may also serve to transmit attached chemical and biological contaminants to waterbodies. Some of the suspended solids are organic materials that decay after they have settled. Too much decaying material can cause oxygen depletion. Toxic chemicals sometime attach to sediments and solids where they can be taken up in the tissue of fish. This can affect the health of humans and wildlife that eat the fish. Turbid waters also interfere with the treatment and use of water as potable water supplies, and can interfere with the recreational use and aesthetic enjoyment of the water.

The state established turbidity criteria in the state water quality standards primarily to protect aquatic life. Two different turbidity criteria are established to protect six different categories of aquatic communities [WAC 173-201A-200; 2003 edition]. In Hangman Creek and its tributaries the following criteria applies:

> To protect the designated aquatic life uses of "Char Spawning/Rearing," "Core Summer Salmonid Habitat," "Salmonid Rearing and Migration" and "Non-anadromous Interior Redband Trout," turbidity must not exceed: A) 5 NTU over background when the background is 50 NTU or less; or B) a 10% increase in turbidity when the background turbidity is more than 50 NTU.

In addition, suspended sediment (a component of total suspended solids or TSS) in Hangman Creek can be controlled using turbidity as a surrogate measure if a strong correlation between them can be established. The water quality standards limit the effect of sediments on existing and designated aquatic life uses in Hangman Creek in the *Toxics and aesthetics criteria.*

(a) Toxic, radioactive, or deleterious material concentrations must be below those which have potential, either singularly or cumulatively, to adversely affect characteristic water uses, cause acute or chronic conditions to the most sensitive biota dependent upon those waters, or adversely affect public health…[(WAC 173-201A-260 (1) (b)]

Temperature

Temperature affects the physiology and behavior of fish and other aquatic life. Temperature may be the most influential factor limiting the distribution and health of aquatic life. Most organisms have fairly narrow ranges of temperatures that can be tolerated. Chemical reactions and metabolism rates also increase with rising temperature, so contaminants can become more toxic. The influence of humans on the terrestrial and aquatic environment can affect aquatic temperature regimes.

Temperature levels fluctuate over the day and night in response to changes in climatic conditions and river flows. Since the health of aquatic species is tied predominantly to the pattern of maximum temperatures, the criteria are expressed as the highest 7-day average of the daily maximum temperatures (7-DADMax) occurring in a waterbody.

In the state water quality standards, aquatic life use categories are described using key species (salmon versus warm water species) and life-stage conditions (spawning versus rearing) [WAC 173-201A-200; 2003 edition]. As mentioned earlier, Hangman Creek must meet criteria to protect salmon and trout spawning rearing and migration.

The temperature criterion for this designation is as follows:

> To protect the designated aquatic life uses of "Salmonid Spawning, Rearing, and Migration, and Salmonid Rearing and Migration Only" the highest 7-DADMax temperature must not exceed 17.5°C (63.5°F) more than once every ten years on average.

The state uses the criterion to ensure that where a waterbody is naturally capable of providing full support for its designated aquatic life uses, that condition will be maintained. The standards recognize, however, that not all waters are naturally capable of staying below the fully protective temperature criteria. When a waterbody is naturally warmer than the criterion, the state provides an additional allowance for additional warming due to human activities. In this case, the combined effects of all human activities must also not cause more than a 0.3°C (0.54°F) increase above the naturally higher (inferior) temperature condition.

In addition to the maximum criteria noted above, compliance must also be assessed against criteria that limit the incremental amount of warming of otherwise cool waters due to human activities. When water is cooler than the criteria noted above, the allowable rate of warming up to, but not exceeding, the numeric criteria from human actions is restricted to: A) incremental temperature increases resulting from individual point source activities must not, at any time, exceed 28/T+7 as measured at the edge of a mixing zone boundary (where "T" represents the background temperature as measured at a point or points unaffected by the discharge), and B) incremental temperature increases resulting from the combined effect of all nonpoint source activities in the waterbody must not at any time exceed 2.8°C (5.04°F).

Special consideration is also required to protect spawning and incubation of salmonid species. Where the department determines the temperature criteria established for a waterbody would likely not result in protective spawning and incubation temperatures, the following criteria apply: A) Maximum 7-DADMax temperatures of 9°C (48.2°F) at the initiation of spawning and at fry emergence for char; and B) Maximum 7-DADMax temperatures of 13°C (55.4°F) at the initiation of spawning for salmon and at fry emergence for salmon and trout.

While the criteria generally applies throughout a waterbody, it is not intended to apply to discretely anomalous areas such as in shallow stagnant eddy pools where natural features unrelated to human influences are the cause of not meeting the criteria. For this reason the standards direct that one take measurements from well-mixed portions of rivers and streams. For similar reasons, do not take samples from anomalously cold areas such as at discrete points where cold groundwaters flow into the waterbody.

Global Climate Change

Changes in climate are expected to affect both water quantity and quality in the Pacific Northwest (Casola et al., 2005). Summer streamflows depend on the snowpack stored during the wet season. Studies of the region's hydrology indicate a declining tendency in snow water storage coupled with earlier spring snowmelt and earlier peak spring streamflows (Hamlet et al., 2005). Factors affecting these changes include climate influences at both annual and decadal scales, and air temperature increases. Increases in air temperatures result in more precipitation falling as rain rather than snow and earlier melting of the winter snowpack.

Ten climate change models were used to predict the average rate of climatic warming in the Pacific Northwest (Mote et al., 2005). The average warming rate is expected to be in the range of 0.1-0.6°C (0.2-1.0°F) per decade, with a best estimate of 0.3°C (0.5°F) (Mote et al., 2005). Eight of the ten models predicted proportionately higher summer temperatures, with three indicating summer temperature increases at least two times higher than winter increases.

Summer streamflows are also predicted to decrease as a consequence of global climate change (Hamlet and Lettenmaier, 1999).

The expected changes coming to our region's climate highlight the importance of protecting and restoring the mechanisms that help keep stream temperatures cool. Stream temperature improvements obtained by growing mature riparian vegetation corridors along stream banks, reducing channel widths, and enhancing summer baseflows may all help offset the changes expected from global climate change – keeping conditions from getting worse. It will take considerable time, however, to reverse those human actions that contribute to excess stream warming. The sooner such restoration actions begin and the more complete they are, the more effective we will be in offsetting some of the detrimental effects on our stream resources.

These efforts may not cause streams to meet the numeric temperature criteria everywhere or in all years. However, they will maximize the extent and frequency of healthy temperature conditions, creating long-term and crucial benefits for fish and other aquatic species. As global climate change progresses, the thermal regime of the stream itself will change due to reduced summer streamflows and increased air temperatures.

The state is writing this TMDL to meet Washington State's water quality standards based on current and historic patterns of climate. Changes in stream temperature associated with global climate change may require further modifications to the human-source allocations at some time in the future. However, the best way to preserve our aquatic resources and to minimize future disturbance to human industry would be to begin now to protect as much of the thermal health of our streams as possible.

Nutrients

Eutrophication is a condition for a lake or stream where plant growth and lower water quality are associated with a high dissolved nutrient input. It can be a natural process that takes hundreds of years as lakes become wetlands and rivers fill valleys with sediment to become slow and marshy. Plants are stimulated by plenty of light and nutrients, low streamflows, and elevated temperatures. Human activity can reduce shade along streams, add nutrients, withdraw water, and increase temperatures. When human-caused acceleration of the plant stimulation is present, it's called cultural eutrophication.

Cultural eutrophication affects periphyton (algae that grow on submerged rocks, plants, and debris) and macrophyte (large aquatic plants) growth in the Hangman Creek during the summer low-flow period. Local water quality problems are associated with the excessive plant growth. Major portions of the creek channel become choked with aquatic weeds, emergent grasses, filamentous algae, and periphyton. Besides affecting habitat and aesthetics in a negative way, the excessive plant growth can cause oxygen supersaturation during the day through photosynthesis and oxygen deficits at night from respiration. The pH values over the day can swing beyond safe levels for fish and macroinvertebrates.

Nutrients do not have numeric state or federal standards for running freshwater systems such as Hangman Creek. In this TMDL nuisance and narrative standards, along with the Spokane River Dissolved Oxygen TMDL load allocations (Ecology, 2007), are used to control phosphorus and nutrients in the watershed. Older USEPA guidelines (USEPA, 1986) of 0.1 mg/L phosphorus have proven ineffective in preventing eutrophication in many watersheds. More recent USEPA ecoregional nutrient guidelines suggest a more region-specific approach (USEPA, 2000a & 2000b).

Hangman Creek is subject to phosphorus, ammonia, and biochemical oxygen demand load allocations determined by the Spokane River and Lake Spokane Dissolved Oxygen TMDL. Since the 1970's, local and state groups have undertaken a long-term effort to control phosphorus in the Spokane River to reduce algal growth in Lake Spokane. The most recent recommended total phosphorus load allocations for Hangman Creek by the Spokane River Dissolved Oxygen Total Maximum Daily Load study (Ecology, 2007) have been presented to the public.

The recent recommendations come after water quality studies, development and adjustments to CE-QUAL-2E, a water quality model of the Spokane River, and meetings with interested parties between 2000 and the present (Ecology, 2007). Allocating phosphorus and nutrient loads in watersheds running through two states with several point source dischargers and nonpoint sources is complex.

Table 4 shows the preliminary recommendations from the Spokane River TMDL study conducted by Ecology in 2000 – 2002 (Ecology, 2004). During the course of the Spokane River and Hangman Creek TMDL studies in 2007, Ecology researchers found that the 2001 monthly streamflows used in the CE-QUAL-2W model for the Spokane River were inaccurate. The average April, May and July streamflows used in Table 4 were only 60% of the actual values, and the August to October flows were 5% to 30% greater than the actual values.

Table 4. Hangman Creek total phosphorus (TP) loads evaluated for the Spokane River Dissolved Oxygen TMDL (Ecology, 2004) with incorrect streamflows.

Month	Average Flow	Critical Condition Total Phosphorus (2001)		Natural Conditions (No Human TP Sources)		Natural Conditions + Total P Load Allocation	
	cfs	mg/L	lbs/day	mg/L	lbs/day	mg/L	lbs/day
April	135.8	0.101	74.0	0.020	14.9	0.023	16.9
May	92.9	0.079	39.4	0.019	9.5	0.022	10.9
June	29.2	0.076	11.9	0.018	2.9	0.021	3.3
July	10.5	0.061	3.5	0.018	1.0	0.021	1.2
August	6.7	0.044	1.6	0.018	0.7	0.021	0.8
September	6.4	0.046	1.6	0.018	0.6	0.021	0.7
October	17.7	0.045	3.1	0.019	1.3	0.022	1.5
Apr – May Average	114.4	0.09	56.7	0.020	12.2	0.022	13.9
Jun – Oct Average	13.1	0.05	4.3	0.019	1.3	0.021	1.5

cfs = cubic feet per second
mg/L = milligrams per liter
lbs/day = pounds per day

Table 5 shows revisions of the monthly load allocations based on the accurate USGS streamflows and other adjustments made to the CE-QUAL-2E model assumptions (Ecology, 2007). These have been presented to the public as part of the TMDL process before submitting the Spokane River/Lake Spokane DO TMDL to EPA for approval. Hangman Creek phosphorus loads to the Spokane River will be evaluated against this latter set of recommendations in this report.

Table 5. Spokane River Dissolved Oxygen TMDL total phosphorus (TP) loads recommended for Hangman Creek with corrected Hangman Creek streamflows (Ecology, 2007).

Month	Average Flow	Critical Condition Total Phosphorus (2001)		Natural Conditions (No Human TP Sources)		Natural Conditions + Total P Load Allocation	
	cfs	mg/L	lbs/day	mg/L	lbs/day	mg/L	lbs/day
April	209.4	0.082	92.0	0.020	22.7	0.054	60.6
May	150.1	0.090	73.2	0.019	15.2	0.050	40.6
June	31.33	0.068	11.5	0.018	3.1	0.049	8.3
July	15.41	0.061	5.1	0.018	1.5	0.045	3.8
August	6.38	0.045	1.6	0.018	0.6	0.039	1.3
September	4.34	0.046	1.1	0.018	0.4	0.042	1.0
October	8.76	0.045	2.1	0.019	0.9	0.045	2.1
Apr – May Average	179.8	0.086	82.6	0.020	19.0	0.052	50.6
Jun – Oct Average	13.24	0.053	4.3	0.019	1.3	0.044	3.3

cfs = cubic feet per second
mg/L = milligrams per liter
lbs/day = pounds per day

Another way to evaluate if phosphorus and nutrient concentrations are being affected by point and nonpoint sources is the USEPA ecoregion reference condition approach. Regions of similar geology, climate, soils, and vegetation should have similar background concentrations of nutrients. The USEPA ecoregions are broken into different levels. Ecology used USEPA's Level III and Level IV ecoregion determinations for this report. Level III ecoregions in the Hangman Creek watershed include the Northern Rockies (15) and Columbia Plateau (10) Ecoregions. Four Level IV ecoregions further subdivide the watershed. The Northern Rockies ecoregion (15) is divided into the Northern Idaho Hills (15v) and Spokane Valley Outwash Plain (15s). The Columbia Plateau ecoregion (10) is divided into the Palouse Hills (10h) and the Channeled Scablands (10a) (USEPA, 2000a; 2000b).

The headwaters lie along the boundary between the Level IV Northern Idaho Hills (15v) and the Palouse Hills (10h). The creek transits through the Palouse Hills to the Channeled Scablands (10a) before entering the Spokane Valley Outwash Plain (15s). The ecoregions suggest that there may be distinctive characteristics in soils and vegetation that could be important for evaluating pollutant loading and transport.

Not enough data have been collected at Level IV, but samples combined from state and federal agencies at Level III are available to estimate a reference conditions (Table 6). The reference concentrations are based on the median of four seasonal 25th percentile values of all data reported across the ecoregion. The USEPA (2000a; 2000b) suggests the 25th percentile is a starting reference concentration until local governments and entities can analyze samples from designated reference streams.

Table 6. USEPA Level III ecoregion reference concentrations relevant to Hangman Creek.

Parameter	Northern Rockies Ecoregion 15		Columbia Basin Ecoregion 10	
	Number of Samples	25th percentile	Number of Samples	25th percentile
Total Phosphorus (mg/L)	150	0.0078	127	0.030
Nitrate + Nitrite Nitrogen (mg/L)	133	0.020	71	0.072
Turbidity (NTU)	74	0.78	41	1.45

However, the research has not been performed to evaluate the effect of the reference nutrient concentrations on resident aquatic communities. For example, the work has not been done for checking if reference concentrations support all beneficial uses and maintain water quality criteria such as dissolved oxygen and pH.

Watershed Description

The Hangman Creek and its tributaries, Rock Creek and Little Hangman Creek, originate in Idaho and flow northeast into Washington. Hangman Creek is a tributary to the Spokane River. The watershed is divided by separate regulatory areas:

- State of Idaho
- Coeur d'Alene Tribal Reservation
- State of Washington.

Ecology has identified the Hangman Creek watershed as a water body with quality and quantity issues. Past water quality studies have shown that state standards for fecal coliform, temperature, pH, and dissolved oxygen are often exceeded (SCCD 1994, 1999, 2000; WDOE, 1998). Past and current land uses within the watershed are varied, and contribute to the problem. Water quality issues, such as stormwater runoff, sedimentation, stream bank erosion, urban development, wetland destruction, and agricultural and forestry practices, are all major concerns for the area.

Agriculture has been the dominant land use in the Hangman Creek watershed since the early 1900s. By the early 1920s, a significant portion of the farmable land had been cleared and cultivated for the production of wheat, barley, peas, and lentils. Thousands of acres of forest and riparian areas were cut and cleared (see below). Miles of stream channel were straightened and new ditches were dug to quickly move water off the farm fields.

These modifications, along with stream meander cutoff by roads, changed the watershed's hydrological response. The system became stressed with heavy sediment loading, poor water quality, and accelerated stream bank erosion. The altered hydrology produces flashy, and sometimes damaging stream flows during the winter and spring months. Peak winter and spring flows are generally 4,000 to 10,000 cubic feet per second (cfs), with flows up to 20,000 cfs. During the summer months, the base flow decreases significantly throughout a majority of the watershed (daily average flows of less than one cfs have been recorded).

To help improve dissolved oxygen levels in Lake Spokane, the level of nutrients, especially phosphorus, will need to be reduced in the discharge from Hangman Creek from April through October. Most conventional pollutants (nutrients, organic matter, and other chemicals) require oxygen for decomposition and/or other chemical reactions. Nutrients also stimulate algae growth, which can contribute to long-term DO depletion when dying algae decomposes.

Several point and nonpoint issues have been identified and discussed through past Hangman Creek water quality studies. Historically, the sources targeted in the Hangman Creek watershed for reduction have been primarily nonpoint sources. Some examples include conservation tillage in croplands, streambank restoration, and riparian restoration.

The Hangman Creek Watershed contains ten permitted facilities. Four of these facilities (Badger Lake Estates, Liberty School District, Hangman Hills, and Upper Columbia Academy) have state wastewater discharge permits to discharge to ground. The six remaining wastewater treatment plants (WWTP) have NPDES permits to discharge to surface water (Table 7).

All facilities perform required water quality monitoring and report results to Ecology to adhere to their NPDES permits. Each of the facility's permits were renewed or extended in 2007. NPDES permits for these facilities allow for discharge of water quality constituents at or near the state water quality standards.

Table 7: Wastewater Facilities with Permits to Discharge to Hangman Creek

Facility	City	Permit Number	Discharges to
Cheney WWTP	Cheney	WA0020842C	Wetland drains to Minnie Creek
Fairfield WWTP	Fairfield	WA0045489C	Rattler Run Creek
Freeman School District	Rockford	WA0045403C	Little Cottonwood Creek
Rockford WWTP	Rockford	WA0044831C	Rock Creek
Spangle WWTP	Spangle	WA0045471B	Spangle Creek
Tekoa WWTP	Tekoa	WA0023141C	Hangman Creek

In addition several entities within the watershed are covered by the Municipal Stormwater Permit. This NPDES permit regulates pollutants carried to waterbodies by stormwater. Spokane County, the City of Spokane, and the Washington Department of Transportation are all Phase 2 municipal separate stormwater sewer system (MS4) permit holders.

Historic Hangman Creek vegetation

The water quality degradation documented throughout the watershed raises questions regarding the historical conditions of the watershed. Pre-settlement watershed conditions were evaluated using historic plant community cover as described in early section line surveys. The section line surveys were part of the Public Land Survey System (PLSS) conducted under standards set forth in the 1785 Land Ordinance (BLM, 2003). The rectangular survey system, also know as the cadastral survey, subdivided public lands into townships, ranges, and sections across the western United States.

The original land surveys of Washington were conducted by the Surveyor General's Office in Olympia, WA during the late 19th Century. Similarly, surveys of the Idaho portions of the watershed were supervised by the Surveyor General's Office in Boise, ID in the early 20th Century. They recorded observations in their field notes, drew plats, and designated boundaries along the line walked. In general, most surveyors' field notes included descriptions of vegetation, landforms, soil type, water availability, and suitability for settlement. These qualitative descriptions of vegetation found in the field notes, along with the hand drawn plats, were used to estimate the historic vegetation cover for the Hangman Creek Watershed.

The historical vegetative communities in the Hangman Creek watershed prior to settlement were significantly different than today (Table 8). The watershed was primarily covered with rolling hills of bunchgrass prairie that extended into scattered populations of Ponderosa pine forests. The Ponderosa pine communities often included a shrub understory such as snowberry and wood's rose. The streams, springs, and drainages were densely vegetated with various shrubs and small trees.

Agriculture has become the dominant land use for the watershed at over 275,000 acres. This more than doubles the pre-settlement prairie and forested areas combined. Forest land cover was reduced between 50 to 75 percent for all sub-watersheds, with the exception of Rock Creek, which was reduced approximately 86 percent. The harvest and conversion of these forested areas, especially in headwater tributaries, probably had significant impacts to the hydrology of the watershed.

Table 8: Land Use Changes in Hangman Creek Watershed (1870-2003)

Sub-watershed	Land Use	Land Uses (percent of sub-watershed area)		Net Change (pre-settlement to current, in percent)
		Pre-settlement	Current	
California Creek	Agriculture	0	55	55
	Developed	0	2	2
	Forested	96	23	-73
	Rock/Transitional	0	0	0
	Shrub/Steppe	4	19	15
	Wetland or Lake	0	0	0
Lower Hangman	Agriculture	0	30	30
	Developed	0	14	14
	Forested	67	18	-49
	Rock/Transitional	0	0	0
	Shrub/Steppe	29	36	7
	Wetland or Lake	3	0	-3
Marshall Creek	Agriculture	0	26	26
	Developed	0	6	6
	Forested	71	34	-37
	Rock/Transitional	0	1	1
	Shrub/Steppe	22	27	5
	Wetland or Lake	5	2	-3
Rock Creek	Agriculture	0	81	81
	Developed	0	1	1
	Forested	71	10	-61
	Rock/Transitional	0	0	0
	Shrub/Steppe	29	7	-22
	Wetland or Lake	1	0	-1
Upper Hangman	Agriculture	0	70	70
	Developed	0	1	1
	Forested	48	21	-27
	Rock/Transitional	0	1	1
	Shrub/Steppe	51	6	-45
	Wetland or Lake	0	0	0

Watershed geologic conditions

Bedrock in the lower watershed is mainly Miocene basalt flows with pockets of Tertiary biotite granite and granodiorite (DNR, 1998). During the Miocene, the basalt flows would periodically dam rivers and form lakes. Material deposited in these lakes formed the siltstones and sandstones of the Latah Formation. Pleistocene glacial deposits produced large amounts of wind-blown silt, known as Loess. This wind-blown silt accumulated up to 200 feet over most of the basalt flows and formed dune shaped hills.

During the late Pleistocene period, lobes from ice sheets in northern Washington, Idaho, and Montana blocked several major drainages and produced extensive lakes. The largest lake produced was Glacial Lake Missoula, located near present day Missoula, Montana, and at one time it covered over 3,000 square miles. Periodically, the ice dams broke and significant floods occurred in Washington, including in the lower Hangman Creek watershed. There were over 40 separate flood events from Glacial Lake Missoula (Waitt, 1980). The floods left major channels in the region, removed the loess deposits covering the basalt, and deposited much of the sand, gravel, cobble, and boulders found in the lower reaches of Hangman Creek.

Easily erodible material is found throughout the Hangman watershed. The unconsolidated material consists of three major deposits. Glacial Lake Missoula flood deposits of sand, gravel, and cobbles; reworked Missoula flood deposits, and the loess deposits found in the upper watershed (Buchanan and Brown, 2003). The Missoula Flood deposits extend from the Spokane River confluence to the Rock Creek confluence. Along with the unconsolidated sediments, the weakly lithified sedimentary rocks of the Latah Formation are also subject to stream erosion.

The Latah Formation consists of fine laminations of silts and clays with low permeability that tends to perch water above the formations. Slumping occurs as water erodes sediment from between the confining silt and clay layers. The silts and clays are resistant bands that tend to form vertical banks above them. Poorly consolidated sands and gravels within the Latah Formation tend to wash out, undercutting and exposing the silt and clay layers. This undercutting can result in block slumps and rapid bank loss.

The Lake Missoula flood deposits consist of sorted to unsorted, silt, sands, gravels, cobbles, and boulders. The unconsolidated material erodes easily along streams, producing steep unstable slopes over 100 feet high. The major type of erosion is toe failure caused by the stream removing the material at the base of the stream bank. Once the toe is removed, the bank is over-steepened. The over-steepened bank fails and deposits large amounts of material directly into the stream. The deposited material is available to be mobilized under most flow conditions (Figure 3).

Figure 3: Material Deposited from Missoula Floods

Post Missoula flood alluvium generally overlies all the other sediment layers. The post Missoula flood material is reworked flood deposits and is unconsolidated and easily eroded. The deposits are generally terraces that originally formed as floodplains when Hangman Creek was downcutting through the flood alluvium. The erosional characteristics are similar to the Lake Missoula flood deposits discussed above, but are more cohesive because a significant amount of sand and gravel has been removed.

Soils within the Hangman Creek watershed have formed from a wide variety of materials. The main soils are deep soils that formed from the silty loess deposits. The soils are generally medium to fine-textured with moderate to slow permeability. The soils have high to moderate water-holding capacity. Other parent materials for the soils include volcanic ash, glacial deposits, alluvium deposited by streams, and material weathered from basaltic, granite, and metamorphic bedrock.

Watershed physiographic provinces

The Hangman Watershed can be divided into three major physiographic provinces (Figure 4); the upper Palouse soil section (headwaters to RM 32.8), the middle basalt canyon section (RM 32.8 to 18.8), and the lower Missoula flood deposit section (RM 18.8 to 0.0). The upper Palouse section extends from the headwaters of Hangman Creek (formed by the Idaho Batholith) through the rolling loess hills of the Palouse region. The upper section represents a river system that is bedrock controlled in many reaches. Some human influence can be seen, but the main channel morphology is generally controlled by existing bedrock.

The middle basalt canyon consists of steep canyons formed as Hangman Creek cut down through the Miocene basalt flows. The stream reaches are generally represented by steep gradients and little floodplain development. Human influence is minor, with some grazing in the accessible reaches.

Hangman Creek then flows through sedimentary hills of sand, gravel, and cobbles deposited by the ancestral glacial lake Missoula Floods. The third physiographic province is dominated by Missoula flood deposits and terraces of reworked Missoula flood deposits. This area represents a young system that has not had time to form an extensive floodplain system by fully reworking the deposited Missoula flood sediments. Human influence is significant with road and housing development from the expanding City of Spokane on the existing floodplain.

Geologic and man-made limitations

Several geologic and climatic conditions combine to provide a unique setting for the Hangman Creek watershed. The environmental conditions include low stream flows during the summer, easily eroded stream banks, and low ground water storage and base flow. These conditions limit what can be done for some areas of the watershed.

Extreme low stream flows in the late summer (below one cubic foot per second) can limit the benefits that would normally occur with the implementation of many of the identified BMPs. The BMPs help reduce loading primarily during higher winter and spring flow events, but they may also help reduce any secondary remobilization during the low flow months. Low streamflow, ground water storage, and base flow also limit riparian and wetland benefits.

Easily eroded stream banks that are unstable at moderate to low flows (such as the sand banks deposited from the Missoula floods) are generally hard to stabilize. BMPs for these banks can be costly, and provide a low cost/benefit ratio.

Anthropogenic limitations include the hydrologic effects of meander cutoffs and stream modifications by roads, agricultural fields, residences, and riparian alteration. Highway 195 has had significant hydraulic effects in the northern physiographic province of the watershed. Several changes to the stream length, vegetation, and meanders have reduced the dissipation of stream energy and increased erosion along this reach of Hangman Creek.

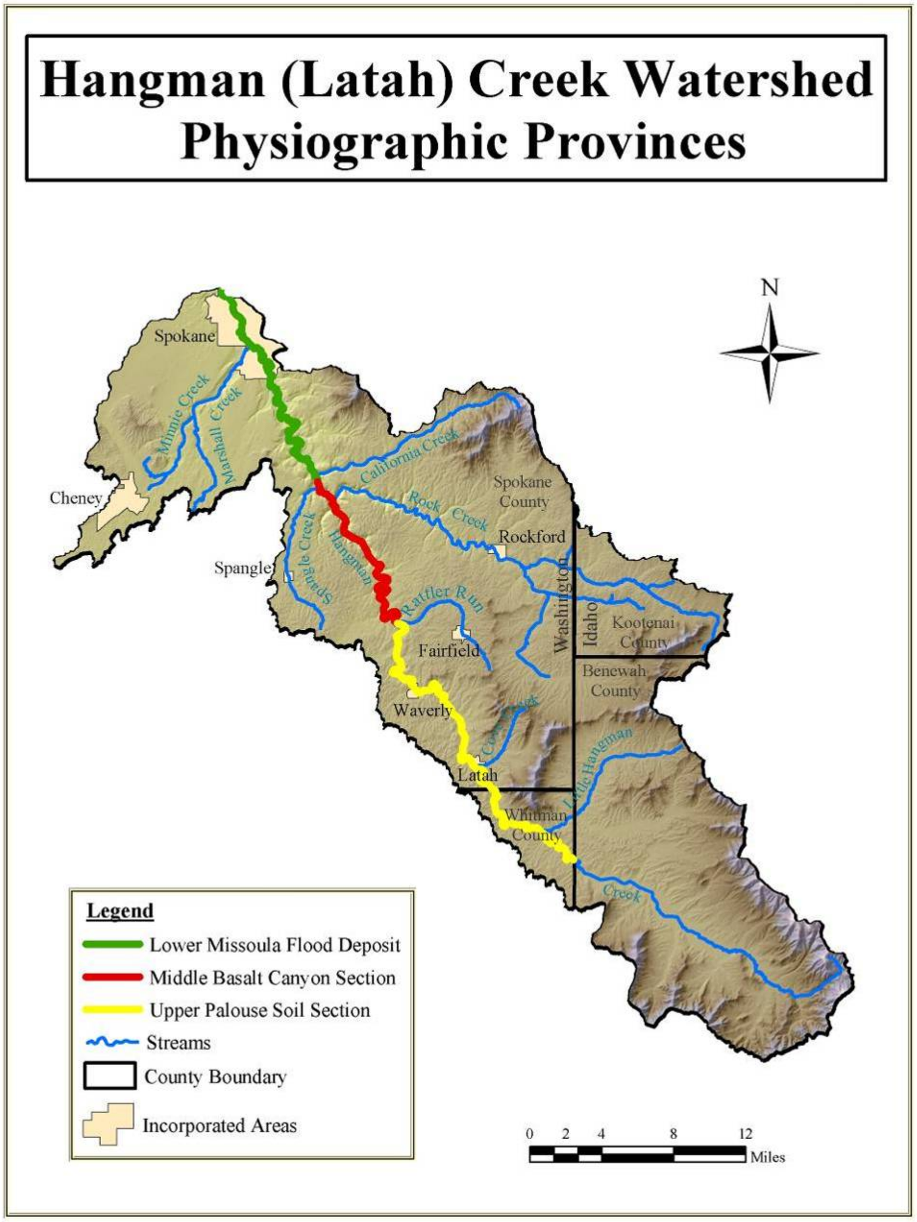


Figure 4: Hangman Creek Physiographic Provinces

Goals and Objectives

Project goals

The goal of this TMDL is to develop a plan to meet water quality standards for fecal coliform bacteria, temperature, and turbidity in Hangman Creek and its tributaries and meet phosphorus load allocations set by the Spokane River Dissolved Oxygen TMDL (Ecology, 2007). The following technical analysis and implementation strategy will accomplish this goal by:

1. Characterizing fecal coliform bacteria, heat, suspended sediment, and phosphorus loading from various parts of the basin.
2. Coordinating phosphorus TMDL load targets for the Spokane River dissolved oxygen TMDL with the Hangman Creek phosphorus TMDL targets.
3. Incorporating previously conducted temperature modeling work into a temperature TMDL.
4. Setting of total maximum daily load (TMDL) allocations on fecal coliform, total phosphorus, temperature, and suspended sediment/turbidity.
5. Outlining an implementation strategy.

Study objectives

Several objectives were set for attaining the project goal. These involved both technical analysis and the implementation process. The technical analysis objectives were led by the Ecology Environmental Assessment (EA) Program project manager and Spokane County Conservation District (SCCD) field staff. The implementation process will continue to be led by the Ecology Eastern Regional Office (ERO) Water Quality Program TMDL lead and SCCD staff.

Objectives for the technical analysis included the following:

- Review background information and historical water quality data to:
  - understand geology, hydrology, climate, land use, and political influences on the water quality problem
  - evaluate additional data needs
  - help determine the seasonal and geographical limits to the problem
  - determine trends
  - focus investigations on potential sources
- Engage local agencies for additional data, expertise, and experience.
- Integrate SCCD field work with work performed by Ecology and other agencies in the basin for efficient use of resources.

Objectives for achieving water quality through implementation activities include the following:

- Inform the community about the TMDL process through meetings and development of a local advisory committee.

- Meet water quality standards by following a locally developed plan.
- Gather input from local residents to create a plan with strategies shown to improve water quality.
- Create and maintain communication with the public and representatives of the various planning processes.
- Partner with local groups to apply best management practices that improve water quality.
- Provide technical and financial assistance when possible.

Field Data Collection

The technical analysis used to evaluate the TMDL was based on historic and recently collected data. Previous studies and monitoring include:

The Washington State Department of Ecology

- Water Quality Monitoring Station #56A070 Hangman Cr at Mouth. This station is considered a long-term station (1970 – 2005).
- Water Quality Monitoring Station #56A200 Hangman Creek at Bradshaw Road. This station was sampled only from October 1998 through September 1999.
- Tekoa Wastewater Treatment Plant receiving water survey in 1988 (Carey, 1989)
- Benthic macroinvertebrate sample collections in Hangman Creek, Marshall Creek, and California Creek in 2004.

The Spokane County Conservation District

- Basin-wide water quality study (1994–1997). Six different mainstem and tributary stations.
- Sediment Study (1998-1999). Suspended sediment and bedload concentrations.
- Paired watershed BMP evaluation data (1997-1998).
- Instream Flow Study. Temperature, flows (2002).
- Seepage run flow and water quality data (2001-2002).

The historic data result from Department of Ecology sampling at their ambient monitoring sites (noted above) and from the Spokane County Conservation District (SCCD) at six stations from October 1, 1994 through September 30, 1997. The SCCD stations sampled were:

- Hangman Creek at the Idaho state line
- Little Hangman Creek
- Rattler Run Creek
- Hangman Creek at Bradshaw Road
- Rock Creek at Jackson Road
- Hangman Creek at Keevy Road

Recent sampling by the conservation district for the development of this TMDL included sampling the Hangman Creek mainstem at 11 sites, Cove Creek at one site, Rock Creek at two sites, California Creek at two sites, Spangle Creek at one site, and Marshall Creek at two sites. Sampling was from December 2003 through August 2004. All data collected under the current sampling were collected under an approved Quality Assurance Project Plan (QAPP, see Appendix A). These data will be discussed in the Results and Discussion section.

Study Methods

Data collection

Water quality and related information from past routine monitoring and intensive studies (1970's – 2002) mentioned in the previous section, *Past and Current Data Collection,* were brought together for this evaluation. Most of the data were collected under quality assurance project plans or with quality control and quality assurance elements (SCCD, 2000 & 2003; Hallock and Ehinger, 2003). Some information was assumed to be collected under standard protocols, but documentation was not verified. For example, the temperature data collected by Hardin-Davis (2003) were assumed to have been recorded and managed properly.

The Spokane County Conservation District (SCCD) performed a comprehensive monitoring study of the watershed from December 2003 to August 2004 (SCCD, 2005a). The study was conducted under an approved quality assurance project plan (SCCD, 2003). The goal of the study was to collect water quality data in preparation for the total maximum daily load (TMDL) evaluations on fecal coliform, total phosphorus, turbidity, and total suspended solids. Monthly and targeted storm event monitoring was accomplished at 19 sites in the watershed (Table 9 & Figure 5). An additional ten sites were monitored only on a few occasions for site-specific purposes (Table 10).

Of the six wastewater treatment plants (WWTP), Fairfield, Rockford, and Tekoa's effluents were sampled monthly from January through July if the WWTP was discharging effluent (SCCD, 2005a). (Table 7). Tekoa WWTP is the only one among the three that discharges to Hangman Creek year around. Cheney WWTP discharges to a wetland connected to Minnie Creek, a tributary of Marshall Creek. Spangle WWTP discharges to Spangle Creek, an intermittent stream. Freeman School District WWTP only intermittently discharges to a tributary in the Rock Creek sub-watershed. Effluent monitoring data from the Cheney's and Spangle's NPDES permit requirements were used for the study.

Temperature monitoring and modeling was contracted to Hardin-Davis, Inc. by the Hangman (Latah) Creek Watershed (WRIA 56) Planning Unit in 2002. Temperature and flow monitoring was conducted by the SCCD for the temperature modeling. The model used was the Stream Network Temperature Model (SNTEMP). Hardin-Davis (2003) conducted a one-day hydrogeologic evaluation, installed mini-piezometers, and tested the hydraulic conductivity of the bed sediments. Physical habitat measurements were taken by Hardin-Davis from five characteristic reaches in the study area. Seepage runs, monitoring of stream flows at several locations over one day, were conducted by the SCCD on three occasions in 2001 and 2002 (SCCD, 2005a).

The temperature monitoring sites for the SNTEMP study are listed in Table 11. The study plan was reviewed by Washington State Department of Ecology Eastern Regional Office Shorelands and Environmental Assistance Program, but no formal quality assurance project plan was written and reviewed. The report was reviewed and accepted by the Hangman Creek Watershed Planning Unit for inclusion into its final water resources management plan (SCCD, 2005b).

Ecology's Environmental Assessment (EA) Program decided the SNTEMP model analyses could be used as the foundation for a temperature TMDL evaluation in the Hangman Creek watershed. The EA Program has historically used a different set of model procedures for temperature TMDLs (Cristea and Pelletier, 2005; Pelletier and Bilhimer, 2004).

The SCCD conducted canopy closure measurements using a densiometer at 19 sites along the creek in September 2006 (Table 12). The measurements were used for ground-truthing the shade values estimated from the aerial ortho-photographs and shade model. Measurements were taken in four directions on the right, left, and middle thirds of the creek on seven transects with convex densiometers. The transects were located at 100, 300, and 500 feet upstream and downstream of a centerline transect (1000 feet area in total). Bank vegetation type, density, average height, overhanging distance data were collected along with basic channel measurements.

Densiometer measurements were converted to percent canopy closure estimates using Timber/Fish/Wildlife stream ambient monitoring field methods (Ralph, 1990). Densiometer readings and canopy closure estimates are summarized in Appendix X.

Data management and analysis

Results of the 2003-2004 Hangman Creek monitoring project were managed according to an approved written quality assurance project plan (SCCD, 2003). All data were reviewed, verified, and validated. Data were submitted to the Department of Ecology Environmental Information Management (EIM) system and are available under User ID G0400196, and Study Name Hangman Creek TMDL Project at http://apps.ecy.wa.gov/eimreporting/Search.asp. The data summary report (SCCD, 2005a) is available on the Department of Ecology Hangman Creek TMDL website at www.ecy.wa.gov/programs/wq/tmdl/hangman_cr/wq_final_report040505.pdf.

Data from several sources for the water quality assessment were managed using Microsoft® Office Excel (2003) spreadsheets. Several tools were used to examine the data. Statistical tests were run using WQHYDRO (Aroner, 2007) and Microsoft® Office Excel (2003) software. Multiple regression analyses were run using an analytical method by Cohn (1988) with SYSTAT software. The Watershed Analysis Risk Management Framework (WARMF) model was run with software provided through the USEPA Office of Environmental Research and originally developed by the Systech Corporation (Systech, 2001).

The WARMF model was constructed and calibrated for the Hangman Creek watershed under an EPA contract by the Cadmus Group and CDM (2007). Geographical information system (GIS), water quality, climatological, and land use data were gathered from the most reliable and recent sources. Model calibration and data refinement continued after receiving the model with additional input provided by Ecology and members of the Hangman Creek Advisory Committee.

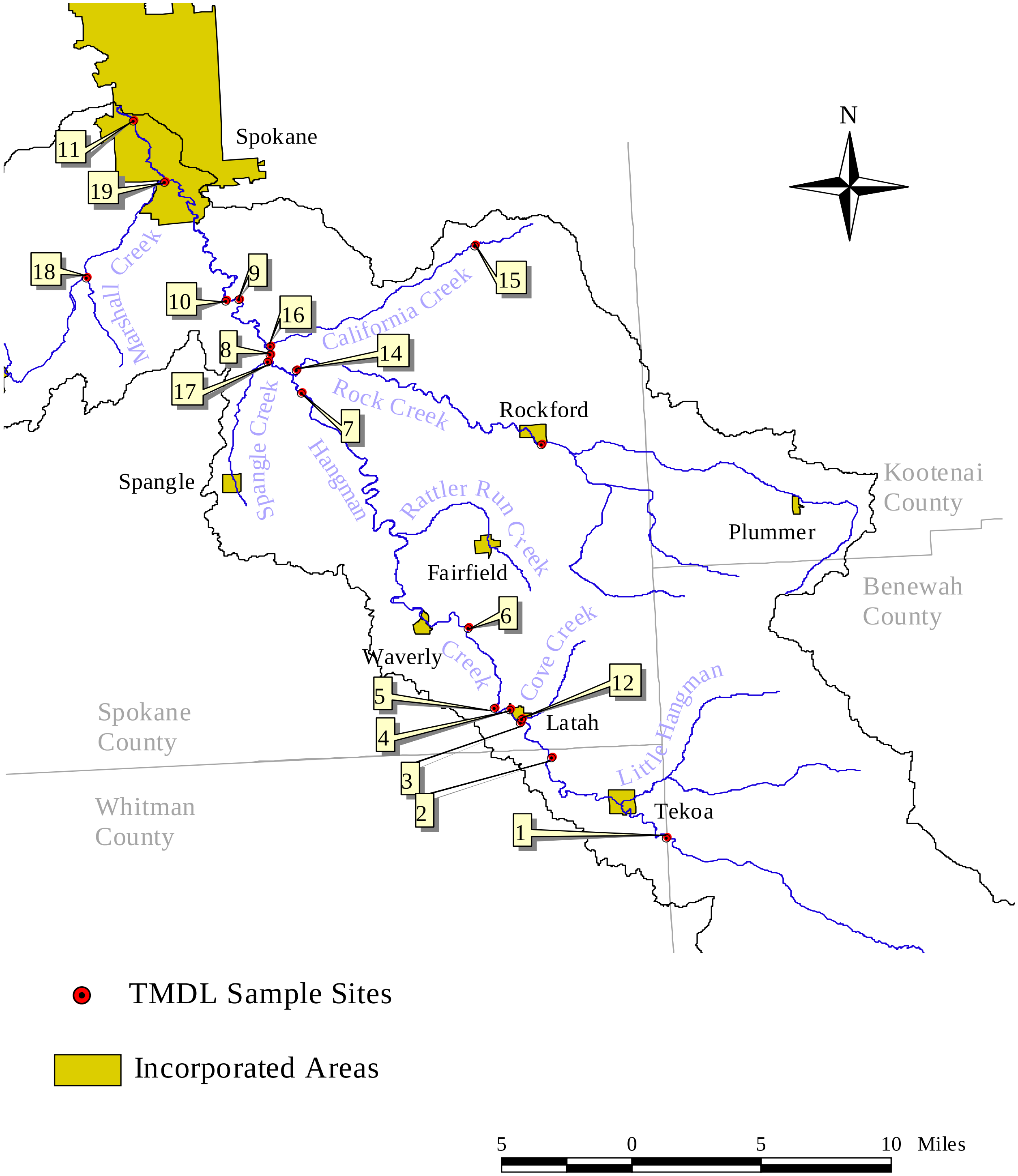


Figure 5. Water quality sampling sites in the Hangman Creek watershed used by the Spokane County Conservation District in 2003-2004.

Table 9. Sites sampled by the Spokane County Conservation District in the Hangman Creek watershed for the total maximum daily load study from December 2003 to August 2004.

Site Name	Site Location (Section, Township, Range)	Site Number on Figure 5
Hangman Creek at the State line	Section 30, T20N, R46E	1
Hangman Creek at Fairbanks Road	Section 9, T20N, R45E	2
Hangman Creek at Marsh Road	Section 30, T21N, R45E	3
Hangman Creek at Spring Valley Road	Section 30, T21N, R45E	4
Hangman Creek at Chapman Road	Section 30, T21N, R45E	5
Hangman Creek at Roberts Road	Section 1, T21N, R44E	6
Hangman Creek at River Mile 21.0	Section 13, T23N, R43E	7
Hangman Creek at Duncan	Section 11, T23N, R43E	8
Hangman Creek upstream of Hangman Valley Golf Course	Section 28, T24N, R43E	9
Hangman Creek downstream of Hangman Valley Golf Course	Section 28, T24N, R43E	10
Hangman Creek at the USGS gage	Section 24, T25N, R42E	11
Cove Creek	Section 30, T21N, R45E	12
Rock Creek at Rockford	Section 33, T23N, R45E	13
Rock Creek at the mouth	Section 12, T23N, R43E	14
California Creek near Marsh Road	Section 18, T24N, R45E	15
California Creek at the mouth	Section 2, T23N, R43E	16
Spangle Creek at the mouth	Section 11, T23N, R43E	17
Marshall Creek at McKenzie Road	Section 22, T24N, R42E	18
Marshall Creek at the mouth	Section 6, T24N, R43E	19

1. All sites were sampled monthly except Hangman Creek at Fairbanks Road, Marsh Road, Spring Valley Road, and Chapman Road.
2. The sites at Fairbanks Road, Marsh Road, Spring Valley Road, and Chapman Road were added to evaluate potential fecal influence from the Town of Latah and from local livestock.
3. Two high flow events were sampled on January 30, 2004 and February 19, 2004. Both events peaked at 4,020 cfs (provisional data) as measured at the USGS station.

Table 10. Special sites sampled by the Spokane County Conservation District in the Hangman Creek watershed for the total maximum daily load study from December 2003 to August 2004.

Sample Location	Site Location (Section, Township, Range)	Site Number on Figure 6	Sample Months
Hangman Creek at North Kentuck Trail	Sec. 17 T22N, R44E	20	Jan. 2004 event
Hangman Creek at Keevy Road	Sec. 8 T22N, R44E	21	Dec. 2003, Jan. 2004, Jan 2004 event, Feb. 2004, Mar. 2004
Stevens Creek at the mouth	Sec. 28 T24N, R43E	22	Feb. 2004, Mar. 2004
Ditch above Madison Road near Valleyford	Sec. 33 T24N, R44E	23	Jan. 2004 event
Ditch below Madison Road near Valleyford	Sec. 33 T24N, R44E	24	Jan. 2004 event
Hangman Creek upstream of Hangman Hills Treatment plant	Sec. 28 T24N, R43E	25	Feb. 2004 event
Hangman Creek downstream of Hangman Hills Treatment plant	Sec. 28 T24N, R43E	26	Feb. 2004 event
Cold Spring near 21st and Inland Empire Way - upper	Sec. 25 T25N, R42E	27	Feb. 2004, Mar. 2004
Cold Spring near 21st and Inland Empire Way - middle	Sec. 25 T25N, R42E	28	Mar. 2004
Cold Spring near 21st and Inland Empire Way - lower	Sec. 25 T25N, R42E	29	Feb. 2004, Mar. 2004

1. Hangman Creek was sampled upstream and downstream of the Hangman Hills treatment plant to evaluate potential fecal and nutrient contributions.
2. The Cold Spring sites were sampled to evaluate the water quality of a significant spring to the Hangman Creek mainstem.
3. Stevens Creek was sampled when there was flow in the creek.
4. Hangman Creek at Keevy Road was the upstream sample point to evaluate potential livestock influence. The site was changed to evaluate a smaller area for influence.
5. The Madison Road sites were sampled to evaluate runoff from a disturbed area where sediment-laden water was flowing below the road.

Table 11. Temperature monitoring sites used to calibrate the SNTEMP model for Hangman Creek (Hardin-Davis, 2003).

Station	River mile	River km	Elevation (ft)	Elevation (m)	Lat (deg)	Lat (RAD)
Hangman Creek at Marne Bridge, Riverside Avenue	0.4	0.6	1730	527	47.65	0.83165
Hangman Creek at Kampas Bridge near Cheney Spokane Road	3.6	5.8	1780	543	47.63	0.83121
Hangman Creek at US 195, D/S of Qualchan Golf Course	4.5	7.2	1795	547	47.62	0.83107
Hangman Creek at Yellowstone Pipe Line	8.8	14.2	1830	558	47.58	0.83049
Hangman Creek at Hangman Valley Golf Course	13.8	22.2	1855	566	47.54	0.82976
Hangman Creek at Valley Chapel Road	18.2	29.3	1887	575	47.52	0.82932
Hangman Creek at Duncan	18.7	30.1	1896	578	47.51	0.82918
Hangman Creek at Latah Road	22.2	35.7	1945	593	47.47	0.82845
Hangman Creek at Keevy Road near Mt. Hope, WA	29.2	47.0	2195	669	47.42	0.82758
Hangman Creek at W. Bradshaw Road near Fairfield, WA	32.9	53.0	2295	700	47.38	0.82700
Hangman Creek at Hays Road near Waverly, WA	35.5	57.2	2325	709	47.36	0.82656
Tributaries						
Marshall Creek at US 195	0.4	0.6	1820	555	47.62	0.83107
California Creek at Elder Road	0.1	0.2	1975	602	47.52	0.82932
Rock Creek at Valley Chapel Road	0.3	0.5	1915	584	47.49	0.82889

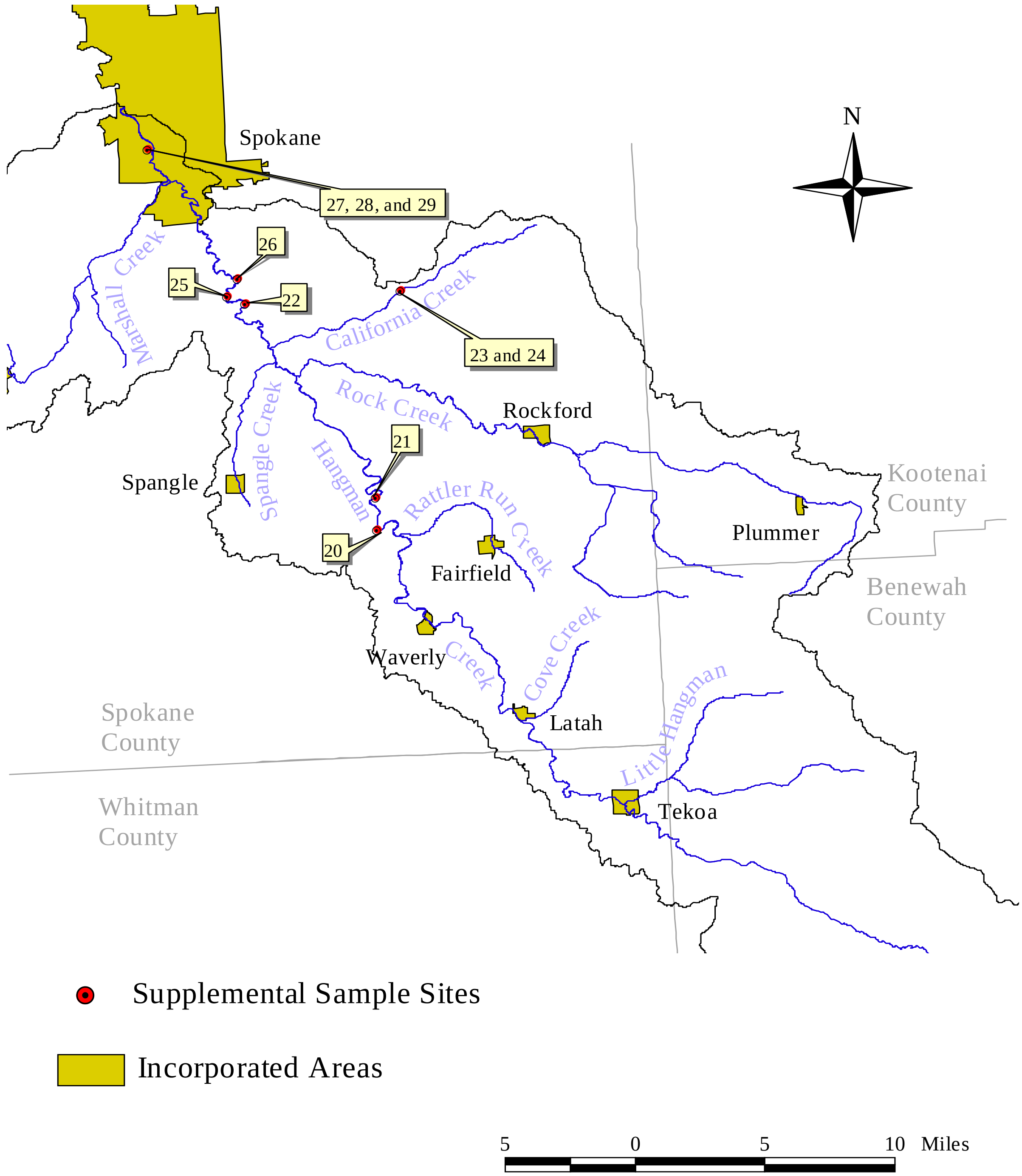


Figure 6. Additional water quality monitoring sites in the Hangman Creek watershed used by the Spokane County Conservation District for special investigations in 2003-2004.

Table 12. The most upstream transect location of 19 sites where canopy cover was measured on September 20 – 22, 2006 by the Spokane County Conservation District. Measurements were taken at seven transects downstream at each site along 1000 feet of Hangman Creek.

Station	River Mile	Description
1	0.6	2000 feet upstream of Marne Bridge
2	3.6	1050 feet upstream of the Avista Bridge
3	4.5	500 feet upstream of Marshall Creek confluence with Hangman Creek
4	5.7	Upstream end of the Bridlewood housing development
5	8.8	500 feet of the Yellowstone Pipeline crossing
6	13.8	Hangman Valley Golf Course
7	18.2	Just downstream of California Creek confluence with Hangman Creek
8	18.7	Approximately 1.5 miles upstream of Valley Chapel Road bridge
9	20.2	Just downstream of Rock Creek confluence with Hangman Creek
10	22.5	Approximately 2 miles upstream of Rock Creek confluence
11	29.2	500 feet upstream of Keevy Road bridge
12	31	1000 feet upstream of North Kentuck Road bridge
13	32.9	500 feet upstream of West Bradshaw Road bridge
14	35.5	500 feet upstream of Hays Road bridge
15	37	1000 feet upstream of Spangle-Waverly Road bridge
16	38	1500 feet downstream of Prairie View Road bridge
17	39.5	Approximately 1.5 miles upstream of Waverly
18	41.6	1000 feet upstream of Roberts Road bridge
19	47	2000 feet upstream of Spring Valley Road bridge

Seasonal Variation and Critical Conditions

Clean Water Act (CWA) Section 303(d)(1) requires that TMDLs “be established at the level necessary to implement the applicable water quality standards with seasonal variations.” The current regulation also states that determination of “TMDLs shall take into account critical conditions for streamflow, loading, and water quality parameters” [40 CFR 130.7(c)(1)]. Finally, Section 303(d)(1)(D) suggests consideration of normal conditions, flows, and dissipative capacity.

The seasonal variation and critical conditions vary somewhat for each of the TMDL pollutants discussed in this report. Therefore, the critical condition is addressed as a separate element during the discussion of each pollutant. The analyses of each pollutant also include comparisons to normal conditions.

Study Quality Assurance Evaluation

The 2003-2004 field data collection used both field blanks and replicate samples to measure the bias and variability. Bias is the systematic error inherent in a method or measurement system. The variability is the random error in independent measurements as the result of repeated application of the process under specific conditions. The quality assurance plan used a random design to estimate the typical or "representative" quality of the environmental data (Appendix _).

Blank samples were submitted to the laboratory to measure the unintentional introduction of the target analyte into the sample. The blank samples consisted of de-ionized water obtained from the Spokane Tribal Laboratory in dedicated amber glass bottles. The blank water was free of the analytes of interest and was used to test for contamination. All blank samples were kept refrigerated until used in the field.

Blank analysis was conducted for total suspended solids, turbidity, nitrite, nitrate, ammonia, and total phosphorus. All blank analysis for total suspended solids, nitrite, and nitrate were below the detection limit. All analyses for ammonia were at the detection limit of 0.01 mg/l. All turbidity analysis had a measurable concentration with a high concentration of 0.87 NTU and a mean concentration of 0.067 NTU. Total phosphorus had one sample below the detection limit of 0.005 mg/l, one at the detection limit, and one sample at 0.013 mg/l (Table 13). None of the phosphorus data were qualified since sample concentrations were much higher than the blank that day. Ammonia blanks are difficult to keep uncontaminated below 0.01 mg/L in a laboratory setting.

Table 13: Blank Analysis Results

Parameter	Blank-1	Blank-2	Blank-3
Total Suspended Solids (mg/l)	<2	<2	<2
Turbidity (NTUs)	0.87	0.32	0.82
Nitrite (mg/l)	<0.01	<0.01	<0.01
Nitrate (mg/l)	<0.01	<0.01	<0.01
Ammonia (mg/l)	0.01	0.01	0.01
Total Phosphorus (mg/l)	0.005	<0.005	0.013

1. NTU is Nephelometric Turbidity Units.
2. mg/l is milligrams per liter.

Replicate samples consisted of two or more samples that were considered to be essentially identical in composition. The replicate samples were collected, processed, transported, and analyzed the same way. Sample volumes, times, equipment, and personnel were kept the same whenever possible. Concurrent replicates, samples that were collected at the same time, were generally collected. Some sequential replicates, samples collected one after another, were collected when concurrent sampling was not possible.

The replicate sample variability was estimated using a piecewise linear model (USGS, 2003). The replicate data were split into two groups based on ranges of mean concentration. The mean standard deviation and relative standard deviation for each range was computed. The results provide estimates of the variability by using either the standard deviation or relative standard deviation; which ever describes the data best. The break point is the sample concentration where the sample result changes from being better described using the standard deviation to being better described using the relative standard deviation (Table 14).

For the parameter limit in Table 14, an exceedance value was estimated based on the replicate analysis. The exceedance value is the value where it can be concluded that the true concentration in the stream did not exceed the listed limit (with a 90 percent certainty). For example, if the nitrate value in a sample was less than 9.84 mg/l, then even with the variability associated with the sampling, it is 90 percent certain that the true value in the stream did not exceed 10.0 mg/l. If the sample value is between 9.84 and 10.0 mg/l, it cannot be concluded (with 90 percent certainty) that the true concentration in the stream did not exceed the 10.0 mg/l limit.

Table 14: Replicate Analysis Results and 90 Percent Confidence Limits

Parameter	Standard Deviation		Relative Standard Deviation		Break Point	90 Percent Certainty Evaluation	
	Statistical Value	Number of Replicates	Statistical Value	Number of Replicates		Limit	Exceedance Value
TSS	0.663	32	13.3	6	8.5	100	85.5
Turbidity	0.338	32	2.52	6	11	50	48.4
Nitrate-N	0.00898	27	1.31	11	3.0	10	9.84
Ammonia-N	0.00265	32	1.39	6	0.04	1.72	1.69
Total P	0.0026	28	2.58	10	0.1	0.1	0.097
Fecal coliform	29.2	34	28	12	150	200	147.2

1. All values are milligram per liter except for fecal coliform, which is colonies per 100 ml, and turbidity which is Nephelometric Turbidity Units (NTUs).
2. TSS is total suspended solids and Total P is total phosphorus as phosphorus.
3. The break point is the sample concentration that divides the replicate samples into two groups, one that uses the standard deviation and one that uses the relative standard deviation to define the sample variance.
4. The exceedance value is the value below which it can be concluded with 90 percent certainty that the true concentration in the stream did not exceed the concentration limit listed in the "Limit" column.
5. The statistical value is the mean standard deviation or relative standard deviation for the number of replicate samples.

The SNTEMP modeling conducted by Hardin-Davis (2003) required calibration to temperature data recorded at 14 sites in the watershed (Table 11). Calibration for the model required some manipulation of wind speed to account for the difference between local and Spokane Airport air temperatures. According to Hardin-Davis (2003), the median absolute error between simulated and observed temperatures was 0.56°C, and 79% of the errors were less than 1°C.

Results and Discussion

Hydrology and climate

Monthly median discharge in Hangman Creek from 1948 to 2005 exhibits a statistically significant, but small, decline (Figure HC1). However over shorter periods of the record, some years show no statistically significant decline in flows (1980 and 2005) or show significant declines (1995-2005). The record over the past 12 years demonstrates a high degree of flow variability (Table HC1) in Hangman Creek. Mean annual discharge varied from 32 to 629 cfs. The historical 90th percentile daily flow was surpassed 108 days in water year 1997, but never in 1994 and only six times in 2005 (Table HC1).

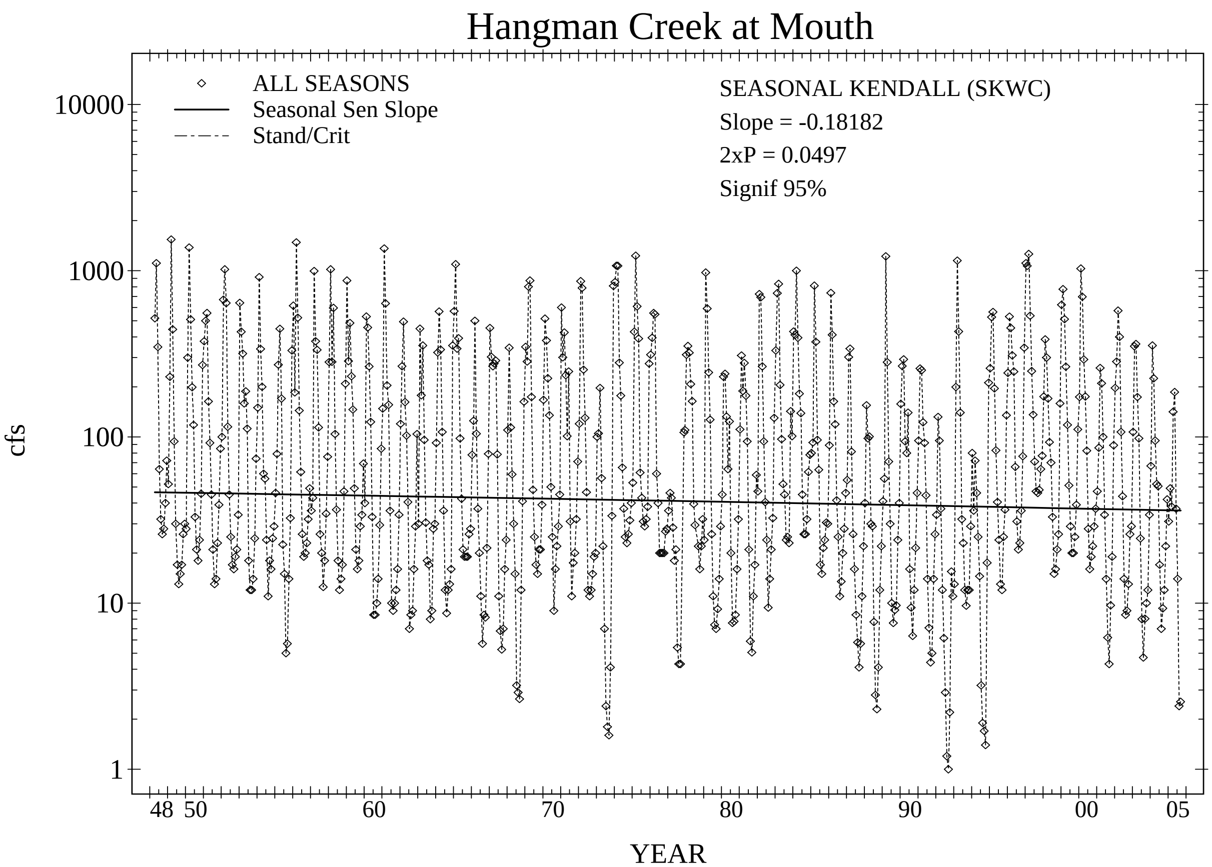


Figure HC1. A Seasonal Kendall trend analysis of monthly median flows for Hangman Creek at the USGS station (12424000).

For TMDL comparison purposes, 1995 and 2004 water years had the most water quality data in the watershed. Water year 2001 is of interest for the Hangman Creek total phosphorus TMDL because it is the critical year designated for the Spokane River dissolved oxygen (DO) total maximum daily load (Ecology, 2007). Phosphorus loads from Hangman Creek are expected to meet load allocations set by the Spokane River DO TMDL during future critical low-flow years (Ecology, 2007).

These three water years, 1995, 2001 and 2004, are representative of very diverse flow conditions. In Table HC1, the mean annual flow in 1995 was double the 2004 flow and three times the 2001 flow. The 1995 water year also had 48 days with mean daily flows over the 10% flow exceeds statistic (567 cfs). This was three times the number of days in 2004 and six times the number of days in 2001.

Table HC1. Monthly and annual daily mean flow statistics and the number of days in the water year when mean discharge exceeded 567 cfs – the 10% flow exceeds statistic (Kimbrough et al., 2006).

Water Year	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Daily Mean	Days > 567 cfs
1994	11	12.1	34.8	93.6	39.5	86.6	56.2	28.5	13.8	4.11	1.96	1.71	32.1	0
1995	2.39	21.8	405.7	590.5	960.2	670.2	194.7	77.7	41.5	22.7	12.3	12.7	247.2	48
1996	25.3	40.8	270.9	482.7	1,776	735.2	628.4	298.4	79.8	34.4	21.5	22.6	362.2	49
1997	41.8	215.9	888.8	2,097	1,376	1,616	664	364.8	143.5	73.8	47.3	46.2	629.1	111
1998	48.5	75.6	96	465.2	431.9	348.7	171.9	218.2	93.3	31.4	15.5	15.7	166.3	23
1999	20.1	37.9	529.9	755.4	1,302	677.2	266.7	126.3	56.2	29.5	20.6	19.8	314.6	52
2000	26	47.1	221.5	242.3	1,254	739.8	454	182.3	87.8	31.2	16.3	18.5	272.8	55
2001	23.4	29.5	36.7	48.1	123	328.7	209.5	150	31.3	15.4	6.36	4.36	83.7	8
2002	9.25	25.5	220.9	534.3	625.4	761.5	397.6	116.5	46.5	15.5	8.62	9.76	228.9	37
2003	13.4	22.9	31.5	230.9	477.7	561.1	195	106.6	29.9	7.93	4.88	7.34	138.8	19
2004	9.31	12.1	35.5	226.9	558	273.7	94	203.9	60.7	17.5	6.71	8.85	124.1	16
2005	14.7	23.5	58.5	142.1	50.6	157.1	161.5	208.4	42.9	13.8	2.53	2.68	73.5	6

In the 2004 water year, the estimated average annual discharge for Hangman Creek at Tekoa was approximately 69.5 cfs, or 56% of the mouth (Figure HC2). The Coeur d'Alene Reservation and Idaho portions of the mainstem Hangman Creek upstream of the gaging site comprise 19.5% of the basin area. The annual average discharge at Duncan (RM 19.9) just below the confluence of Rock Creek was 103 cfs, or 83% of the mouth that included 80% of the basin area.

A continuously recording gage was not installed at the Idaho border in 1995. Based on regressions of paired instantaneous measurements, the average daily discharge at the Idaho border in 1995 was estimated to be 82 cfs. That flow would mean a 33% contribution from the upper watershed to the streamflow volume leaving Hangman Creek. Most likely the greater snow pack, lower temperatures, and higher rainfall increased the apparent contribution from the lower watershed compared to 2004.

Portions of Rock Creek are also in the Coeur d'Alene Reservation. The streamflow contribution to Rock Creek from these areas has not been evaluated. Together the Rock Creek, Little Hangman Creek watershed, and the upper mainstem areas in the Coeur d'Alene Reservation and Idaho comprise about 35% of the watershed area. However, the total streamflow contribution across the border to Hangman Creek may be more substantial in some years since Hangman Creek above Tekoa can contribute 56% in some years.

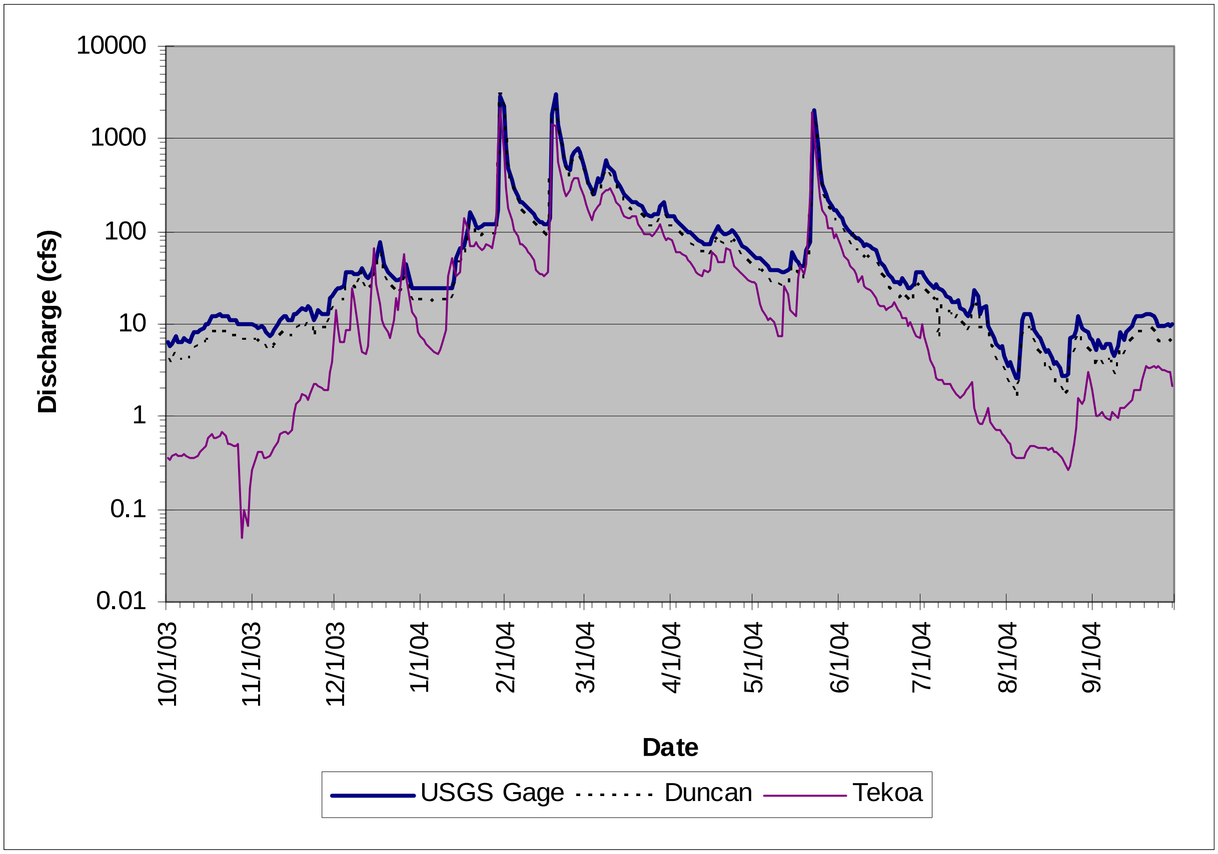


Figure HC2. Comparisons of average daily discharge along Hangman Creek at Tekoa river mile (RM) 54.6, Duncan Road at RM 19.9, and the USGS gage at RM 0.8 for water year 2004.

Air temperatures and precipitation during the three water years were also very different from one another. In 1995, maximum monthly average temperatures were higher than normal in fall and winter, but lower than normal in the summer (Figure HC3). In contrast, 2001 had lower than normal temperatures in fall and winter and higher temperatures at the end of summer. Maximum monthly average temperatures in 2004 were near normal except for a warm early spring. Precipitation volumes were higher than average in 1995, lower than average in 2001, and about average in 2004 (Figure HC4).

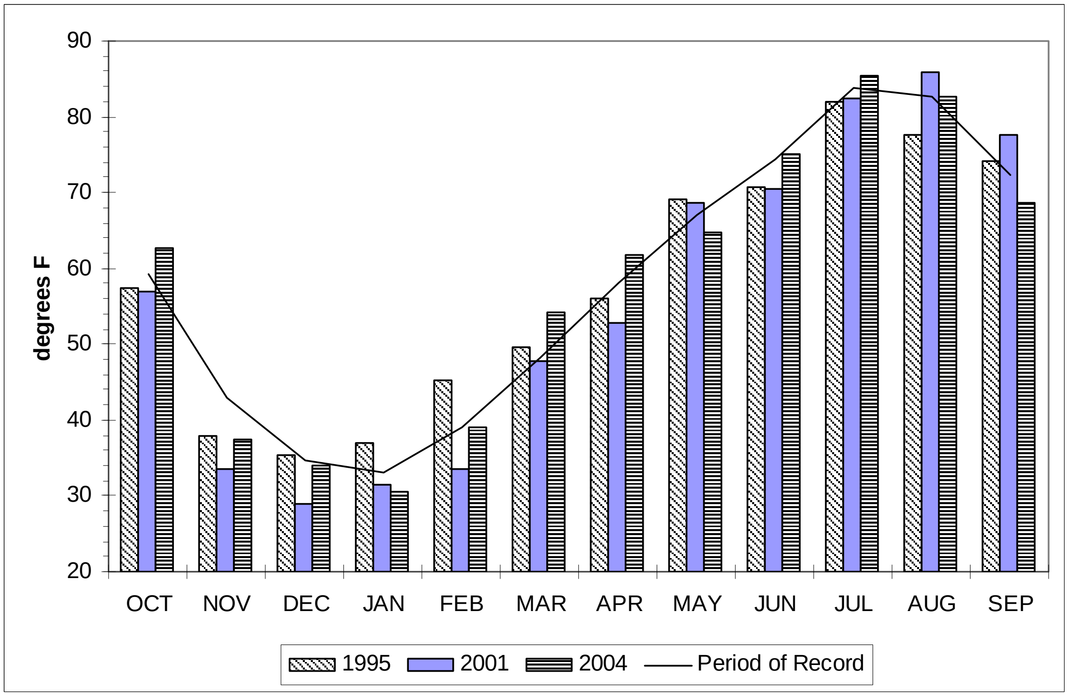


Figure HC3. A comparison of long-term average (Period of Record) monthly maximum temperatures to those in water years 1995, 2001, and 2004 at the Spokane Airport (Western Regional Climate Center, 2006).

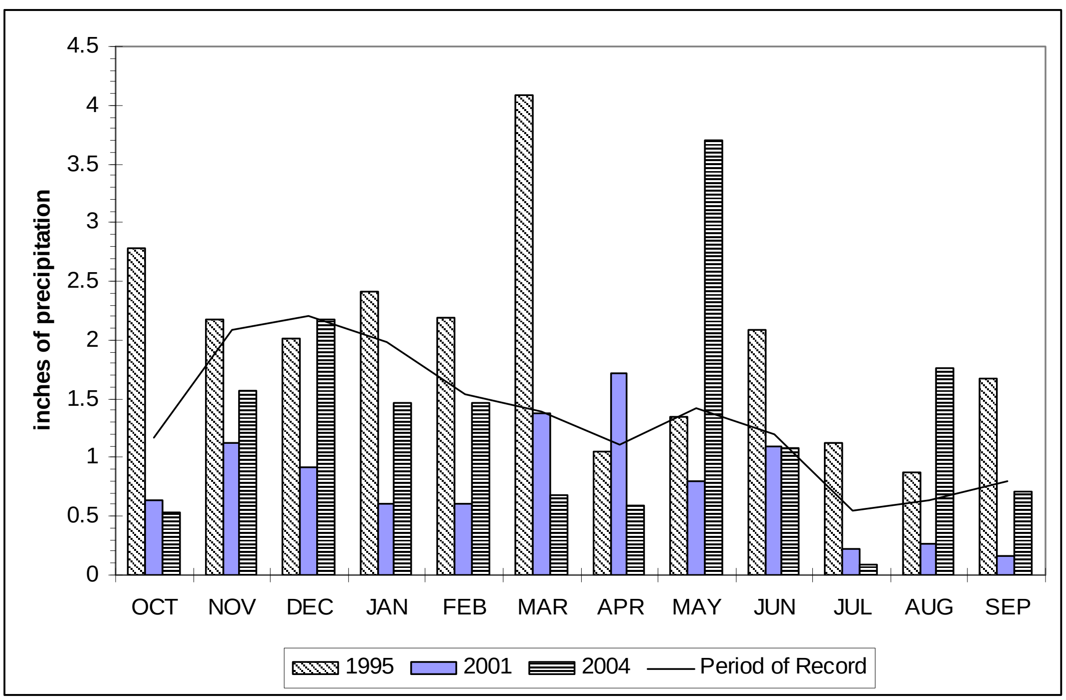


Figure HC4. A comparison of long-term average (Period of Record) monthly rainfall volumes to volumes in water years 1995, 2001, and 2004 at the Spokane Airport (Western Regional Climate Center, 2006).

Climate and river flow records are less complete in the upper watershed in Idaho. The climate record in Plummer and Tensed Idaho follow the patterns of the Spokane Airport for the months and years they are available (Western Regional Climate Center, 2006). Both Plummer and Tensed tend to have lower maximum monthly temperatures and more rainfall than Spokane because of their higher altitude (approximately 200' to 300') with resulting orographic effects.

TMDL Analyses

Fecal coliform

Areas of concern

Fecal coliform (FC) criteria violations have been documented at the mouth of Hangman Creek since the 1970's (Ecology, 2006). The Ecology ambient monitoring site (56A070) is sampled monthly and has provided a long-term record of the bacterial quality of the creek. The monthly FC counts have varied widely over a particular water year and from year to year. As with most water quality data, long-term annual trends and seasonal trends change somewhat with the period of record chosen to analyze.

The trends over the past 10 years (1995 – 2005) of FC counts, flows, and calculated FC loads are shown in Figures FC1 – FC3. The FC counts at the mouth continue to periodically exceed the fecal coliform criterion but there has not been a significant trend. The monthly discharge (Figure FC2) has shown a significant decreasing trend that has influenced the FC load trend (Figure FC3). This implies that flow is not necessarily the most dominant factor on fecal coliform counts.

FC counts at the mouth of Hangman Creek are especially relevant to recreational uses and human health because of easy public access through the city park located at the confluence of Hangman Creek and the Spokane River. Elevated counts also could affect downstream public access areas on the Spokane River. The reach based on the monitoring site data is on the 303(d) list for not supporting recreation uses.

As previously shown in Tables 1, 2 and 3, Spokane County Conservation District (SCCD) monitoring studies (SCCD, 1999; 2000) have documented other reaches of Hangman Creek with FC criteria violations as well:

- Hangman Creek at Bradshaw Road (RM 32.9),
- Rock Creek at Jackson Road,
- Little Hangman Creek,
- Hangman Creek at the border with Idaho (RM 54.3), and
- Tributary to Hangman Creek at Griffith Road

The Tekoa wastewater treatment plant (WWTP) study by Carey (1989) also identified reaches below Tekoa (RM 53.5) which have remained on the 303(d) list from the 1990's to the present.

The most recent monitoring study conducted by the SCCD (2005) identified more reaches of the mainstem Hangman Creek with suspected FC criteria violations (SCCD, 2005a):

- Spring Valley Road
- Marsh Road
- Roberts Road

- Keevy Road
- Latah Creek Road at River Mile 21.4
- Duncan Road

All sites had FC values exceeding criteria over the 2003 – 2004 survey period (Table FC1). When all samples of the survey were used for the statistical analysis, none of the sites exceeded the geometric mean criteria except Keevy Road, but most had 10% of their values, or the 90th percentile of the values, greater than the 200 count/100 mL criterion. The Keevy Road site was sampled only five times during the study so the statistics are not as representative as for most other sites.

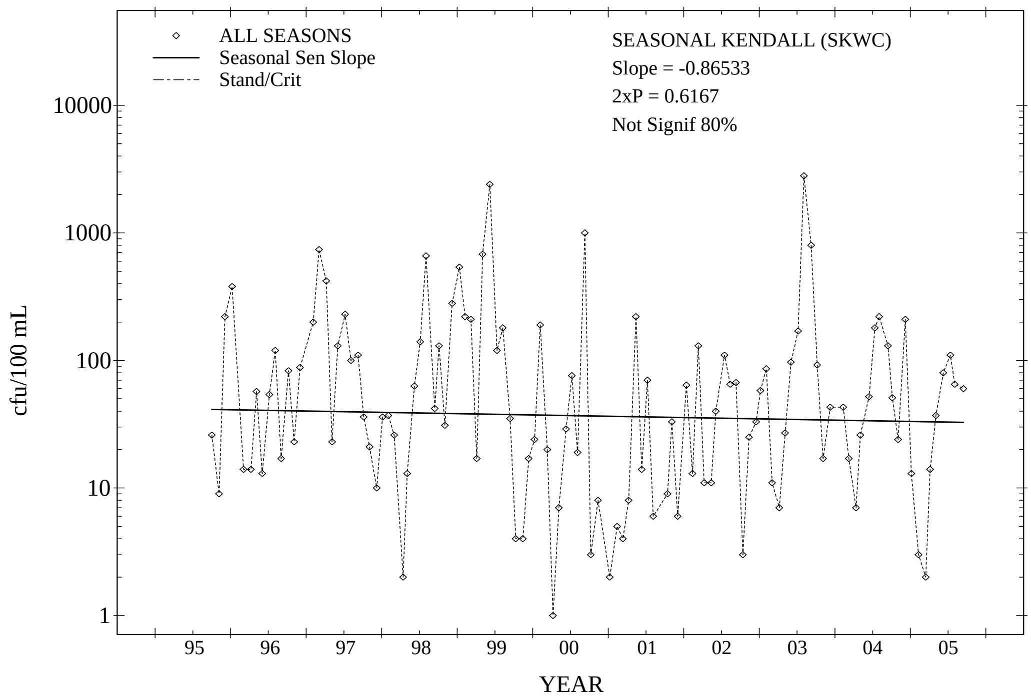


Figure FC1. Trend of fecal coliform counts (concentration) in samples collected from Hangman Creek by the Washington State Department of Ecology at site (56A070) 1995 - 2005.

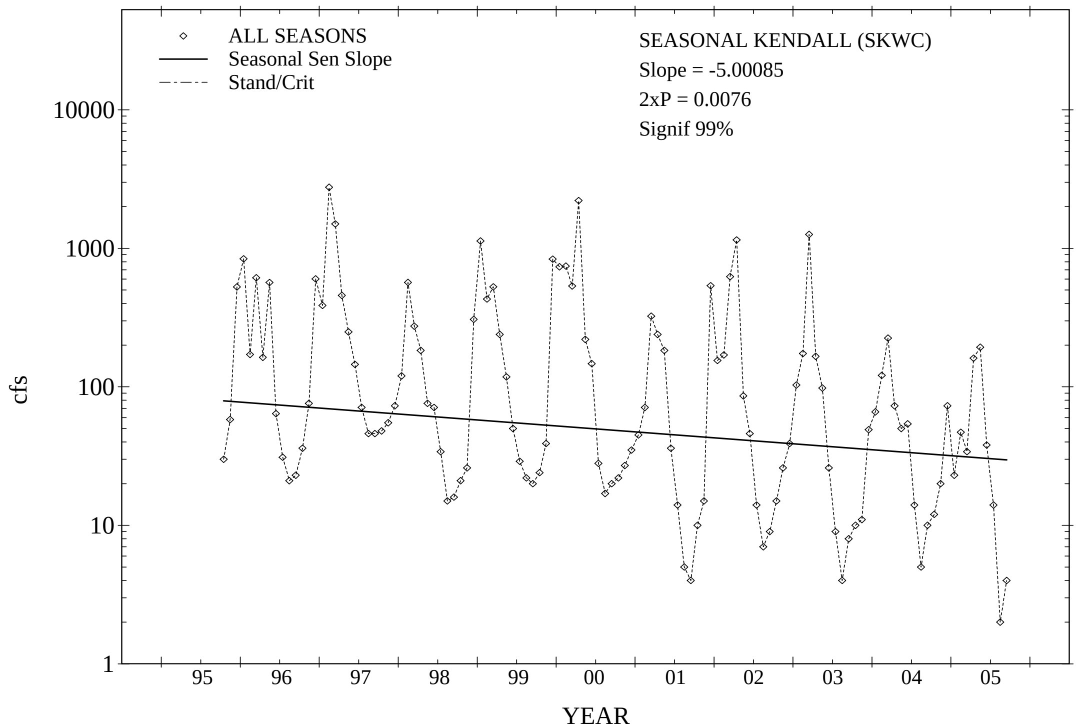


Figure FC2. USGS discharge trend on Hangman Creek at mouth (12424000) 1995 – 2005.

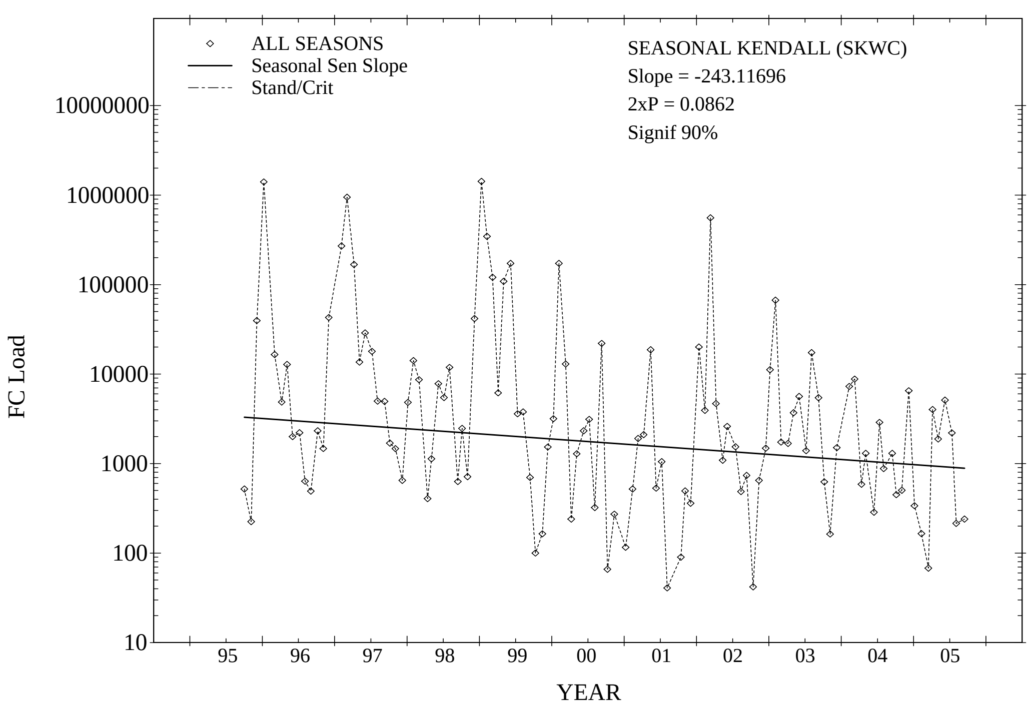


Figure FC3. Fecal coliform load trend on Hangman Creek at the mouth (56A070) 1995 – 2005.

Table FC1. A statistical summary of the fecal coliform (FC) bacteria results from samples collected by the Spokane County Conservation District in the Hangman Creek watershed from December 2003 to August 2004. FC counts not in compliance with state FC criteria are indicated with bold type. Map identification refers to Figure 5.

Map ID	Site	No. of Samples	Geo. Mean cfu/100 mL	90th %tile cfu/100 mL	> 200	Average Load cfu/day x 10^{10}
1	Hangman Creek at State line	11	64	**505**	**27%**	120
2	Hangman Creek at Fairbanks Rd.	7	46	**454**	**29%**	54
12	Cove Creek	11	84	**1003**	**45%**	0.6
4	Hangman Creek at S. Valley Rd.	7	68	**567**	**29%**	80
3	Hangman Creek at Marsh Rd.	7	33	**334**	**14%**	49
6	Hangman Creek at Roberts Rd.	11	40	**316**	**18%**	70
5	Hangman Creek at Chapman Rd.	7	64	**227**	**14%**	45
21*	Hangman Creek at Keevy Rd.	5	**173**	**4670**	**60%**	170
7	Hangman Creek at River Mile 21.4 on Latah Creek Rd.	11	55	**520**	**27%**	67
14	Rock Creek at Mouth	11	94	**509**	**27%**	22
13	Rock Creek at Rockford	11	36	**609**	**27%**	7.4
17	Spangle Creek	7	25	**276**	**14%**	0.12
8	Hangman Creek at Duncan Rd.	11	36	**247**	9%	78
16	California Creek at Mouth	11	15	178	9%	0.32
15	California Creek at Marsh Rd.	11	28	**390**	**18%**	0.14
19	Marshall Creek at Mouth	11	30	**204**	9%	0.18
18	Marshall Creek at McKenzie Rd.	11	9	113	9%	0.3
11	Hangman Creek at USGS gage**	19	49	**439**	**18%**	47

* Map identification is on Figure 6.

** Includes samples collected by Ecology at the co-located long-term monitoring site #55A070.

Tributaries also were not in compliance with FC criteria at sites on Cove Creek, Rock Creek, Spangle Creek, upper California Creek, and lower Marshall Creek (Table FC1). These join Little Hangman Creek and Rattler Run on the list of tributaries that require further work (Table 2). Of the monitored tributaries, only upper Marshall Creek and lower California Creek met state criteria during the TMDL survey period.

The discharge monitoring reports (DMRs) data for the wastewater treatment facilities (WWTPs) in the watershed were reviewed as part of the TMDL study. All of the permits, except for Tekoa WWTP, have FC limits more stringent than for best conventional technology. The WWTP data from the DMRs imply that some WWTPs have had FC disinfection problems in the recent past. Effluent FC concentrations at Fairfield and Tekoa were out of NPDES permit compliance for several months in 2004 and 2005 (Table FC2). The FC data in the DMRs for the Cheney WWTP are not counts discharged to receiving water, but to the wetland.

Stormwater runoff is also a source of concern for FC loading to Hangman Creek and its tributaries. Fecal loading from stormwater sources could not be specifically identified in this study. The stormwater permit monitoring requirements for Washington Department of Transportation (WDOT), the City of Spokane and Spokane County were not in effect when the monitoring program was designed. Urbanized areas, Highway 195 and Interstate 90 are located in the lower Hangman Creek where increases in FC loading were observed during the 2003 – 2004 TMDL surveys. Future characterization of stormwater sources will be necessary.

In summary, more comprehensive watershed sampling in 2003 and 2004 has shown that most areas of the mainstem of Hangman Creek and many tributaries have FC problems. On the other hand, few sites appear to have chronic FC violations. The FC problems may have been worse in the past. Although low-flow conditions at the mouth of Hangman Creek can result in high FC counts, storm events at any time of the year can cause many sites to violate state criteria. Some WWTPs had recent FC disinfection problems that require attention. Stormwater sources will require future characterization and treatment options.

Table FC2. Fecal coliform NPDES permit limits and the number of times limits were exceeded at six wastewater treatment plant (WWTP) facilities in the Hangman Creek watershed.

Facility	Average Monthly Permit		Average Weekly Permit		Data Record Reviewed
	Limit	# Exceed	Limit	# Exceed	Dates
Cheney WWTP	50	1	100	3	Jan 2003 – Dec 2005
Fairfield WWTP	100	5	200	7	Dec 2004 – Dec 2005
Freeman School District	100	1	100	3	Jan 2003 – Dec 2005
Rockford WWTP	100	1	200	2	Jan 2003 – Dec 2005
Tekoa WWTP	200	4	400	9	Dec 2002 – Dec 2005
Spangle WWTP	100	0	200	1	Jan 2003 – Dec 2005

Critical conditions

A long-term (1989 – 2004) evaluation of flow conditions when FC criteria violations occur at the mouth of Hangman Creek is shown in Figure FC4. The FC loads for individual monthly samples collected at Ecology site 56A070 are compared to FC loads compliant with the 100 cfu/100 mL and 200 cfu/100 mL criteria along a frequency flow graph. November to May FC violations tend to occur when flows are greater than 571 cfs, or less than 10% of the time on a long-term discharge basis. June to October violations appear to be evenly distributed along the lower half of the frequency curve.

Often sources of FC contamination accumulate loads on land or along riparian corridors until a storm event can wash them into the creek. Another mechanism may be FC organisms adsorb to sediment, settle to the bottom of the creek, and then resuspend as flows and water velocities increase. According to research, FC organisms can remain viable in sediments for months under favorable conditions (Sherer, Miner, Moore, and Buckhouse, 1992).

In 2003 and 2004, the elevated 90th percentile values at most sites were usually the result of targeted storm events. The storm events that were monitored in 2003 and 2004 occurred in the winter and in the summer (SCCD, 2005a). Although this appears to be contrary to the relationship just shown between flows and FC counts with long-term trends, historical data suggests that elevated FC counts have occurred during storm runoff periods throughout the period of record at the mouth of Hangman Creek.

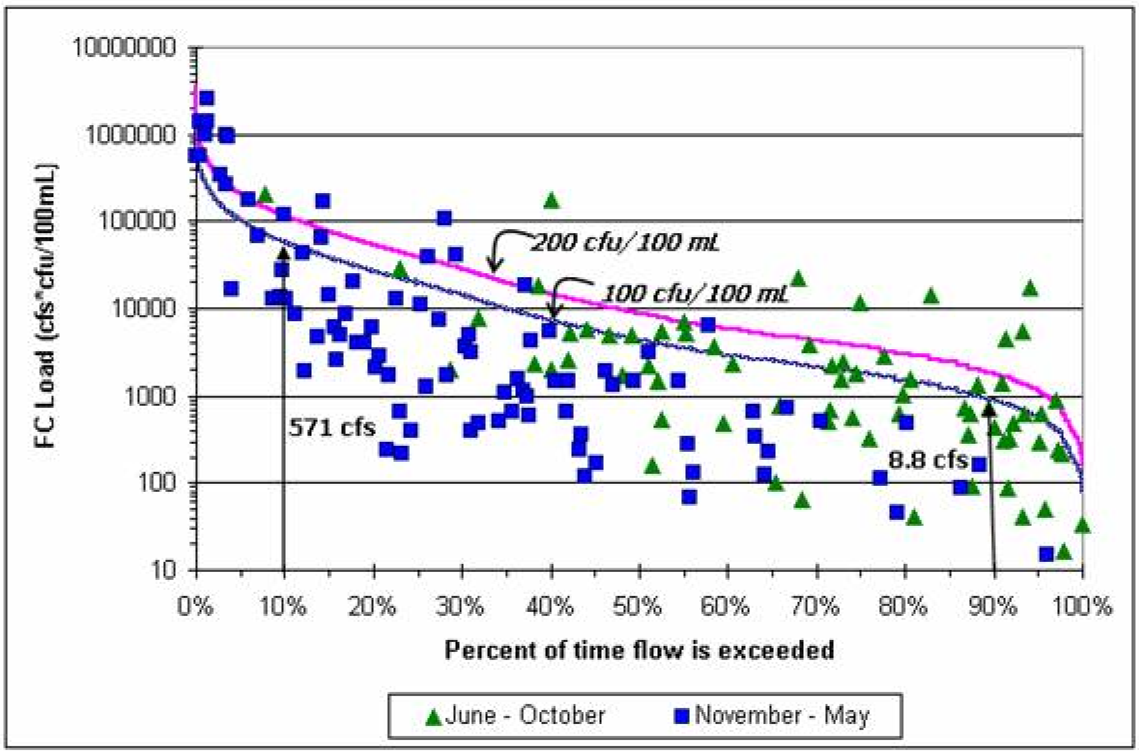


Figure FC4. Seasonally-stratified fecal coliform (FC) loads (▲■) calculated from data collected from 1989 to 2004 at the mouth of Hangman Creek (Ecology site 56A070). Loads are compared to criteria-compliant FC loads (solid lines) along a frequency curve for flows from 1948 to 2004.

In 2003-2004, Rock Creek, Cove Creek, Spangle Creek, upper California Creek, and Hangman Creek at Keevy Road and at River Mile 21.4 had elevated FC counts occurring at times other than storm events. Earlier work by the SCCD (1999; 2000) also had similar findings. The elevated counts at these sites suggest either a fixed source or nonpoint sources other than surface run-off from properties adjacent to the stream network, e.g., access by wildlife or livestock, pet waste dumping, or malfunctioning on-site or public sewage systems.

A simple estimate of average FC loads with and without the storm event data suggests that storm events may have been responsible for over 90% of the FC loading in the mainstem at the Idaho border. The percentage attributed to storm event loads at the mouth of Hangman Creek was about 70%. In most tributaries, the range was 20% - 60%. The mouth of Rock Creek had only 14% of the estimated average FC load attributed to the storm events.

Researchers have found that storm events are often responsible for the majority of the annual pollutant load in a watershed. However, the water year 2004 was drier than normal in Hangman Creek, so the apparent influence of the storm events may have been exaggerated compared to average conditions in the watershed. Estimates on the 1995-1997 FC data suggest that storm events were a less influential on the annual FC loads in Hangman and Rock Creeks.

Considering the likelihood of storms at any time of year and the paucity of data for many sites, no critical condition for FC has been established for most sites in the watershed. Data for Hangman Creek at State line and Hangman Creek at the Mouth were numerous enough to evaluate by season, and loading capacities were developed on the most critical months for chronic FC criteria violations:

- Hangman Creek at State line — August – January
- Hangman Creek at the Mouth — July – September

The months used for the critical condition at these two sites somewhat followed the relative influence of stormwater and low streamflows on FC counts. FC counts at the site at the mouth appear to be less dominated by storm runoff, so drier months with lower streamflows are critical. The site at the Idaho border appeared to have more elevated FC counts during both low flow (August – October) and from storm runoff (November – January).

Analytical framework

The fecal coliform evaluation is approached conservatively to account for its wide daily and seasonal variability. All of the FC sample counts from a site are tested for their statistical distribution characteristics. Most follow a lognormal distribution, so the following assumptions are made with reference to water quality criteria:

- The geometric mean of the samples is equal to the transformed mean of the lognormal distribution.
- The transformed 90th percentile of the lognormal distribution is equal to the value that not more than 10% of the counts should exceed.

In most cases these assumptions are more conservative for designating the 90th percentile or ‘not more than 10% of the values to exceed’. The variability of the distribution is considered in the calculating the 90th percentile.

The Statistical Rollback Method (Ott, 1997) was used to determine if the FC distribution statistics for individual sites meet the water quality criteria in the Hangman Creek watershed. The method has been successfully applied by Ecology in other FC bacteria TMDL evaluations (Cusimano and Giglio, 1995; Joy 2000, Coots, 2002, Joy and Swanson, 2006).

The method is applied as follows:

The geometric mean (approximately the median of the lognormal distribution) and 90th percentile statistics are calculated and compared to the FC criteria. If one or both do not meet the criteria, the whole distribution is “rolled-back” to match the most restrictive of the two criteria. The 90th percentile criterion is usually the most restrictive. So, rolling-back means maintaining the slope of the original lognormal FC data distribution with the 90th percentile of the distribution set at 200 cfu/100 mL.

The rolled-back geometric mean and 90th percentile FC value then define the “target” FC distribution for the site. (The term target is used to distinguish these estimated numbers from the actual water quality criteria.) The amount a distribution of FC counts is “rolled-back” to the target values is the estimated percent of FC reduction required to meet the FC water quality criteria and contact recreation water quality standards. A detailed graphical example is shown in Appendix x.

The rollback was applied to the most representative distribution after taking several analytical steps. At sites with historical data, both step trends and monotonic trend analyses were performed on FC counts and streamflows to determine the most recent and stable dataset, i.e. to ensure that high water and drought years are represented equally. Trend analyses, tests for seasonality, and statistical tests for lognormal distributions were performed using WQHYDRO, a statistical software package for environmental data analysis (Aroner, 2007). The geometric mean and 90th -percentile statistics for various subsets of data were then calculated and compared to determine a critical season at each site, and to calculate the target TMDL values.

It is important to remember that the FC TMDL targets are only in place to assist water quality managers in assessing the progress toward compliance with the FC water quality criteria. Compliance is measured as meeting water quality criteria. Any waterbody with FC TMDL targets is expected to meet both of the applicable geometric mean and ‘not more than 10% of the samples’ criteria and meet beneficial uses for the category.

A Beales ratio estimator formula (Dolan et al., 1981) was used to calculate the annual FC loads at sites with adequate pollutant and streamflow data (Appendix x). The Beales formula provides a better annual or seasonal estimate of pollutant loads compared to the average instantaneous load obtained from a few sampling events. The average instantaneous load was calculated when continuous discharge data were absent or could not be estimated from nearby gauging data.

Fecal coliform load model comparisons

We also compared the FC load estimates at the mouth of Hangman Creek using three different methods. We compared the results from the Beales formula, a simplified monthly mass loading calculation, and a multiple regression model (Cohn, 1988). Comparing the results from the three methods provided an estimate of the FC load variability.

The three methods of calculating FC loads at the mouth of Hangman Creek came into fairly close agreement for most months (Figure FC5). The Beales and simple average monthly loads were more similar to each other than to the Cohn multiple regression model results. Average monthly FC load estimates were most similar during the low-flow periods. As may have been expected, variable streamflow during the fall and spring months resulted in wider divergence of FC loads.

The critical season for FC criteria violations at the mouth of Hangman Creek is July through September. FC loads are not at their peak at that time, but setting reduction targets to water quality standards should reduce FC loads during higher flows if source controls are implemented. Figure FC6 illustrates the anticipated effect on the FC distribution at the mouth of Hangman Creek (Figure FC4) after implementing FC source reductions by 72% estimated by the roll-back method. The reductions may be most successful at higher flows, but FC violations at lower flows will also be reduced to acceptable levels.

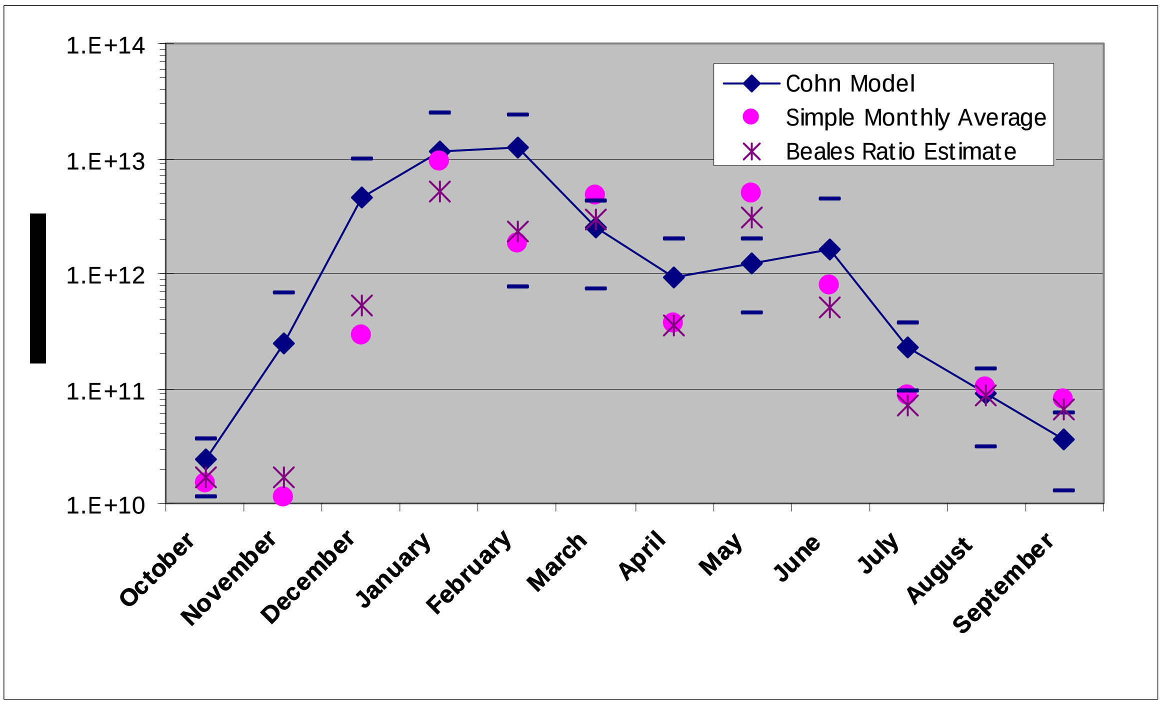


Figure FC5. A comparison of monthly fecal coliform average loads at the mouth of Hangman Creek from October 1989 to September 2005 (Ecology site 56A070).

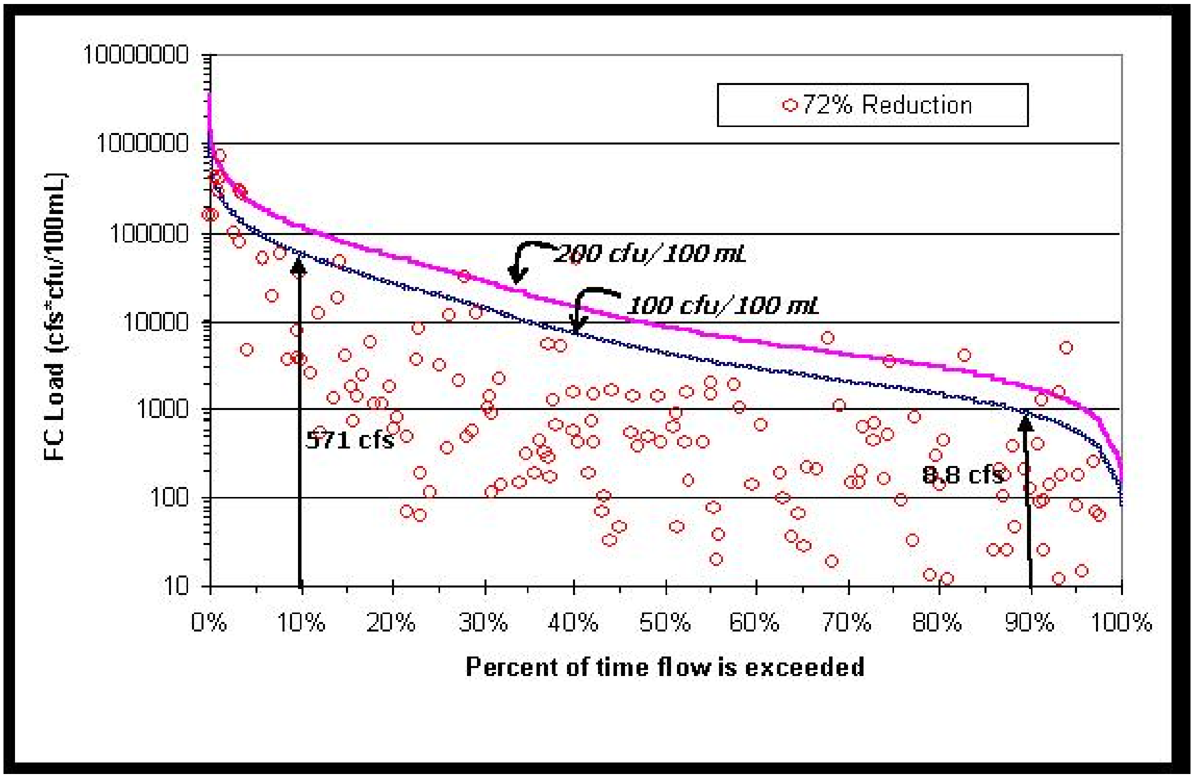


Figure FC6. Application of a 72% reduction in fecal coliform loading sources to data previously collected at the mouth of Hangman Creek to demonstrate its anticipated effectiveness.

Loading capacity

Definition and determination

USEPA regulations define loading capacity as the greatest amount of pollutant loading that a waterbody can receive without violating water quality standards [40CFR§130.2(f)]. The loading must be expressed as mass-per-time or other appropriate measure. Also, the critical conditions that cause water quality standard violations must be considered when determining the loading capacity.

Washington State fecal coliform (FC) bacteria TMDLs use a combination of mass-per-time units and statistical targets to define loading capacities. This is necessary since mass-per-time units (loads) do not adequately define periods of FC criteria violations. Loads are instructive for identifying changes in FC source intensity between sites along a river, or between seasons at a site. However, FC sources are quite variable and different sources can cause FC criteria violations under different loading scenarios (e.g., poor dilution of contaminated sources during low-streamflow conditions or increased source loading during run-off events).

The statistical targets provide a better measure of the loading capacity during the most critical period. The FC loading capacity at Hangman Creek watershed sites is based on the applicable two statistics in the state FC criteria (e.g., the geometric mean and the value not to be exceeded by more than 10% of the samples). As discussed earlier in the *Analytical Framework* section, the 90^{th} percentile value of samples is used in TMDL evaluations for the latter criteria statistic. The FC TMDL target loading capacities in the following table are either the criteria, or they are statistics that estimate the reductions necessary to meet the criteria (Table FC3).

Table FC3. The loading capacities and target fecal coliform (FC) statistics for Hangman Creek watershed sites.

Map ID	**River Mile**	Location	Critical Period*	No. Samples	FC Reduction	FC Target Capacity (cfu/100mL)	
						90^{th} % tile	Geomean.
1	**57.4**	Hangman Creek at State Line	Aug - Jan	20	72%	200	36
2	**50.4**	Hangman Creek at Fairbanks Road		7	56%	200	20
4	**47.0**	Hangman Creek at Spring Valley Road		7	65%	200	24
3	**47.3**	Hangman Creek at Marsh Road		8	32%	200	24
6	**41.5**	Hangman Creek at Roberts Road		12	27%	200	36
13+	**32.9**	Hangman Creek at Bradshaw Road		35	60%	200	30
21++	**29.2**	Hangman Creek at Keevy Road		12	78%	200	11
7	**21.4**	Hangman Creek at River Mile 21.4		12	56%	200	20
8	**18.6**	Hangman Creek at Duncan Road		12	10%	200	27
11	**0.8**	Hangman Creek at Mouth	July - Sept	43	72%	200	40
		Little Hangman Creek at Tekoa		21	67%	200	31
12		Cove Creek		12	79%	200	19
		Unnamed Tributary at Griffith Road	Nov-May	7	25%	200	22
		Unnamed Tributary at Roberts Road	Jun-Oct	7	61%	200	19
		Rattler Run		31	85%	200	12
13		Rock Creek at Rockford		11	67%	200	12
		Rock Creek at Jackson Road		33	68%	200	16
14		Rock Creek at Mouth		12	70%	200	34
17		Spangle Creek		7	28%	200	18
15		California Creek at Marsh Road		12	49%	200	14
16		California Creek at Mouth		12	23%	200	15
18		Marshall Creek at McKenzie Road		11		200	9
19		Marshall Creek at the Mouth		12	54%	200	19

* Blanks denote lack of a specific critical period

+ Map identification refers to Figure 5.

++ Map identification refers to Figure 6.

The percentage reduction values in the table indicates the relative degree the waterbody is out of compliance with criteria (i.e., how far it is over its capacity to receive FC source loads and still provide the designated beneficial uses). Sites representing reaches or tributaries that are currently meeting their loading capacity do not have a FC reduction value. Sites that require aggressive reductions in FC sources will have a high FC percentage reduction value (greater than 60%), while sites with minor problems will have a low FC percentage reduction value (less than 30%).

Since the loading capacity and statistical values are based on the critical condition, the tables include the critical period. The reductions do apply to the entire year, but the more stringent TMDL reduction protects water quality for the most critical season. If there is no critical period, then no seasonal changes were noted in the available data so entire record was used. The critical season provides water quality managers and local citizens a sense of what type of FC sources may require the most work.

Load and wasteload allocations

This Total Maximum Daily Load (TMDL) technical evaluation of the Hangman Creek watershed demonstrated that contact recreation is impaired in most areas that were investigated and that fecal coliform (FC) load reductions are necessary. The estimated load allocations (LA) and wasteload allocations (WLA) are shown in Table FC4. Most of the FC load sources are nonpoint in nature and require load allocations. The point sources in the basin are assigned wasteload allocations based on their NPDES permit limits, or on adjusted permit limits if water-quality based limits are necessary.

Table FC4. Fecal coliform load allocations and wasteload allocations for sites and point sources in the Hangman Creek watershed.

Hangman Creek Reach, Point Source, or Tributary	Listing ID	WLA or Load Allocation (cfu/day)	Current Load (cfu/day)	Target Reduction (%)	Target Basis WLA/LA WQ criterion
Hangman Creek at State Line	41992	5.6×10^{11}	2.0×10^{12}	72%	10% > 200
Little Hangman Creek	41994	5.6×10^{10}	1.7×10^{11}	67%	10% > 200
Tekoa WWTP		1.2×10^{9}	3.9×10^{9}	70%	NPDES permit
Hangman Creek at RM 53.8	6726	6.2×10^{11}	2.2×10^{12}	72%	10% > 200
Hangman Creek at Fairbanks Road	46497	2.4×10^{11}	5.4×10^{11}	56%	10% > 200
Hangman Creek at Spring Valley	46493	2.8×10^{11}	8.0×10^{11}	65%	10% > 200
Hangman Creek at Marsh Road	45306	3.3×10^{11}	4.9×10^{11}	32%	10% > 200
Cove Creek	45629	1.3×10^{9}	6.0×10^{9}	79%	10% > 200
Unnamed Tributary at Griffith Road	45553	3.0×10^{8}	4.1×10^{8}	25%	10% > 200
Unnamed Tributary at Roberts Road	45110	1.5×10^{8}	3.0×10^{8}	61%	10% > 200
Hangman Creek at Roberts Road	45242	5.1×10^{11}	4.0×10^{11}	27%	10% > 200
Hangman Creek at Bradshaw Road	16863	6.8×10^{11}	1.7×10^{12}	60%	10% > 200
Rattler Run at Mouth	45310	2.3×10^{9}	1.5×10^{10}	85%	10% > 200
Rattler Run Nonpoint Sources		1.3×10^{9}	1.2×10^{10}	89%	10% > 200
Fairfield WWTP		9.6×10^{8}	3.0×10^{9}	68%	NPDES permit
Hangman Creek at Keevy Road	45268	3.7×10^{11}	1.7×10^{12}	78%	10% > 200
Hangman Creek at River Mile 21.4	45250	2.9×10^{11}	6.7×10^{11}	56%	10% > 200
Rock Creek at Mouth	45312	6.6×10^{10}	2.2×10^{11}	70%	10% > 200
Rock Creek at Jackson Road	41996	2.4×10^{11}	7.5×10^{11}	68%	10% > 200
Rockford WWTP		2.8×10^{8}	2.9×10^{8}	3%	NPDES Permit
Freeman School District		1.3×10^{7}	2.0×10^{7}	15%	NPDES Permit
Rock Creek at Rockford	46317	2.4×10^{10}	7.4×10^{10}	67%	10% > 200

Spangle Creek at Mouth Spangle Creek Nonpoint Spangle WWTP	45347	8.6×10^{8} 8.4×10^{8} 2.2×10^{7}	1.2×10^{9} 1.2×10^{9} 2.2×10^{7}	28% 29% NPDES permit (no reduction)	10% > 200 10% > 200
Hangman Creek at Duncan Road	45251	7.0×10^{11}	7.8×10^{11}	10%	10% > 200
California Creek at Mouth California Creek at Marsh	41991 46287	2.5×10^{9} 7.1×10^{8}	3.2×10^{9} 1.4×10^{9}	23% 49%	10% > 200 10% > 200
WA Dept. of Transportation		NC	NC	72%	10% > 200
Spokane(City & County) stormwater		NC	NC	72%	10% > 200
Marshall Creek at the Mouth Marshall Creek at McKenzie Cheney WWTP*	41995 46270	8.3×10^{8} 3.0×10^{9} 1.6×10^{9}	1.8×10^{9} 3.0×10^{9} 1.6×10^{9}	54% no reduction required NPDES permit (no reduction)*	10% > 200
City of Spokane stormwater WLA		NC	NC	72%	10% > 200
Hangman Creek at Mouth	45260	2.3×10^{10}	8.2×10^{10}	72%	10% > 200

* Cheney WWTP WLA based on effluent FC count to the wetland being the same if discharged to Minnie Creek.

Monitoring sites along Hangman Creek and on tributaries in the watershed become points for load allocations. Unless point sources with WLAs are present upstream, nonpoint source LAs and required levels of reduction assume that FC sources are nonpoint in nature. Nonpoint sources are often difficult to separate from background sources like wildlife and waterfowl. No attempt with this dataset has been made to allocate FC loads separately to background sources. For example, beaver activity at the mouth of Cove Creek may be taking all of the LA for lower Cove Creek. This will not be known until more intensive monitoring is conducted upstream.

Point sources were evaluated based on monitoring reports from the past four years. Some changes have taken place to improve disinfection procedures and reduce the frequency of permit violations. The Ecology permit managers and WWTP operators should continue to work together to ensure consistent disinfection and meet current permit limits. None of the permits appeared to require more stringent limits to achieve instream FC criteria. The Cheney WWTP limits are based on FC counts to the wetland since the effluent from the wetland has not discharged to Minnie Creek.

Fecal coliform stormwater loads in urban areas are considered capable of occurring at any time. Therefore, municipal stormwater FC wasteload allocations were not specifically reserved for a ‘storm’ season. Although not specifically investigated in this study, the stormwater wasteloads are assigned in Table FC4 until better data can be obtained. They are based on the FC reductions (72%) necessary to achieve water quality standards in lower Hangman Creek during the critical period.

Washington Department of Transportation (WDOT), the City of Spokane, and Spokane County are jurisdictions with Phase 2 stormwater permits. They are expected to locate and evaluate outfalls in their systems in the TMDL area. They will work with Ecology permit managers to maintain or upgrade best management practices to reduce FC loading to the Hangman Creek watershed.

Hangman Creek, Little Hangman Creek and Rock Creek will require FC load reductions coming across the Idaho border into Washington. Ecology encourages the US Environmental Protection Agency, the Coeur d’Alene Tribe, and the State of Idaho to work together to reduce the upstream FC loads.

Conclusions and recommendations

The following conclusions and recommendations are based on this fecal coliform TMDL evaluation:

Conclusions

- Fecal coliform loads at the mouth of Hangman Creek appear to be decreasing over the long-term, but this may be a result of declining streamflows rather than declining FC counts.
- Fecal coliform counts exceed state criteria at several locations in the watershed, but no location appeared to be chronically degraded.
- Storm events at any time of the year result in elevated fecal coliform counts in many reaches of the watershed, and are the main cause of criteria violations that require TMDL load reductions.
- The sources of FC contamination in the watershed are not obvious, but may include livestock riparian access, malfunctioning on-site septic systems and WWTP disinfection systems, waterfowl and wildlife, and stormwater runoff.
- Disinfections practices at some WWTPs have improved over the past few years and now consistently comply with NPDES permit limits.
- Implementing a 72% FC load reduction at the mouth of Hangman Creek during the months of July through September should be adequate to reduce FC loads throughout the year.

Recommendations

- The mouth of Hangman Creek and reaches where informal swimming occurs should be the highest priority areas for FC abatement action.
- Ecology will need to work with the USEPA, Coeur d'Alene Tribe and Idaho to reduce FC loads in the upper Hangman Creek, Little Hangman Creek, and Rock Creek.
- Most sites require more intensive spatial and temporal monitoring to better identify sources of FC contamination.
- Phase 2 stormwater permit holders need to evaluate their systems and work with Ecology permit managers to ensure FC reductions are achieved.

Allocation for future growth

Hangman Creek watershed primarily has an agricultural land base. Conversions of agricultural land to residential or non-commercial farms are of concern in the watershed. Stormwater and animal-keeping practices at non-commercial farms are the most likely sources of FC loads from these land use conversions. These future potential sources should be adequately addressed by this TMDL in the following ways:

- The FC load reductions recommended in the TMDL have large margins of safety that will require significant implementation measures to ensure compliance. These margins of safety are adequate to require implementation measures that reduce the impact of FC loads from stormwater and non-commercial farms.

- Most of the future growth is expected to occur in the lower watershed where stormwater quality is controlled by jurisdictions under Phase 2 permits that have FC Wasteload Allocations that must be met. Phase 2 jurisdictions are required to control all new stormwater sources within their boundaries.

Margin of safety

The federal Clean Water Act requires that Total Maximum Daily Loads (TMDLs) be established with margins of safety (MOS). The MOS accounts for uncertainty in the available data, or the unknown effectiveness of the water quality controls that are put in place. The MOS can be stated explicitly (e.g., a portion of the load capacity is set aside specifically for the MOS). But, implicit expressions of the MOS are also allowed such as conservative assumptions in the use of data, application of models, and the effectiveness of proposed management practices.

Implicit MOS elements were applied to analyses to provide a large MOS for Hangman Creek fecal coliform FC TMDL evaluation. The FC database in most areas of the watershed was limited, so this increased the level of uncertainty in the FC loads and receiving water quality. The FC reductions and allocations are conservatively set to protect human health and beneficial uses to the fullest extent. The following are conservative assumptions that contribute to the MOS.

- The statistical rollback method was applied to FC data from the most critical season and resultant TMDL target annual FC load reductions are more stringent than would be required under the listed Washington State *Primary Contact* and *Secondary Contact Recreation* FC criteria (i.e., the geometric mean or concentration not to be exceeded in more than 10% of the samples is more stringent than 100/200 cfu/100 mL).

- Since the variability in FC concentrations during low-flow conditions and storm events is usually quite high, the TMDL targets and percent reduction estimated by the statistical rollback method are conservative, especially if a 90^{th} percentile is the critical criterion. In these cases, the high coefficient of variation of the log-normalized data can produce a 90^{th} percentile value for the population greater than any of the sample results used to calculate the value. This is especially true at sites with fewer than 20 data.

- The FC loading capacities and TMDL target load reductions for the several mainstem and tributary sites were conservatively calculated by including a historical data set with more frequent criteria violations.

- Instream die-off rates were not considered to calculate the cumulative FC loads in Hangman Creek.

- The Phase 2 stormwater permit wasteload allocations were included to focus future permit-holders' activities even though the critical conditions for most FC problems in the lower watershed, where most stormwater permits are located, are during low-streamflow conditions when stormwater flows are less likely to be generated.

- The WWTP reductions to meet wasteload allocations are based on past disinfection problems. Meeting the NPDES permit limits should no longer be a problem since disinfection procedures have been improved at all WWTPs.

Temperature

Areas of concern

Problems with elevated temperatures in the Hangman Creek watershed have been under-reported. The Washington State Department of Ecology 2004 Statewide Water Quality Assessment has only three temperature listings in the Hangman Creek watershed (Ecology, 2005). The mouth of Hangman Creek is on the 303(d) list as impaired for monthly data with instantaneous measurements taken by Ecology (Figure T1). Hangman Creek near Tekoa (RM 53.2) and at Bradshaw Road (RM 32.9) are listed as Category 2, waters of concern. Both are based on older instantaneous measurements collected by Ecology in 1988 (Carey, 1989) and 1999 (Ecology, 2005).

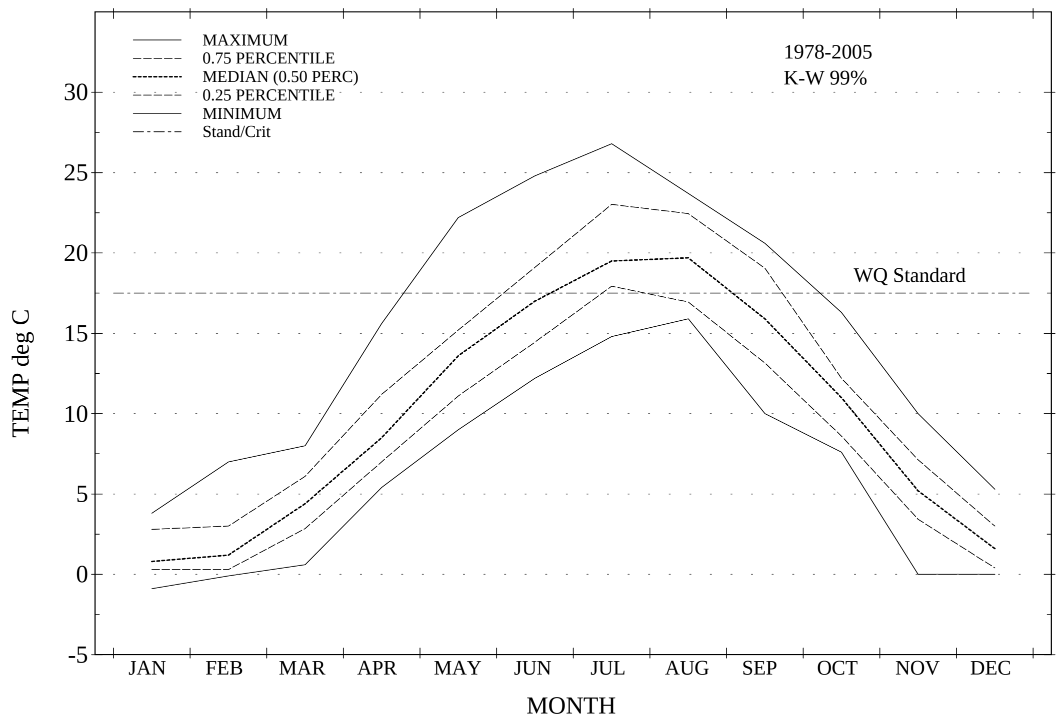


Figure T1. Monthly statistics for instantaneous temperature measurements taken at the mouth of Hangman Creek from 1978 to 2005 (Ecology Station 56A070).

A trend analysis of the monthly temperature data at the mouth of Hangman Creek is not possible because instantaneous measurements have not been collected at the same time of day over the period of record. Nor have they been collected at the time of the peak water temperature. As may be reasonably assumed, water temperatures are often highly influenced by the time of day.

Elevated temperatures in the watershed are now a documented, widespread, seasonal problem. Spokane County Conservation District surveys in 1994 through 1997 measured instantaneous water temperatures greater than 17.5°C in Hangman Creek at the Idaho state line (RM 55) and at Bradshaw Road (RM 32.9), the mouth of Little Hangman Creek, the mouth of Rattler Run Creek, and Rock Creek at Jackson Road (SCCD, 1999). At very low discharge conditions in 2004, Cove Creek, California Creek, and Marshall Creek also exhibit temperatures above 17.5°C (Appendix, Table x - borrow from Rick's Data Report).

Continuous temperature monitoring data collected for the Hardin-Davis (2003) SNTEMP model calibration recorded elevated temperatures from June through September 2002 along Hangman Creek from Hays Road (RM 34.5) to the mouth (Figure T2). Average weekly temperatures exceeded 17.5°C through most of the monitored reach from mid-June to mid-September. The upper reaches of the creek were especially susceptible to elevated temperatures.

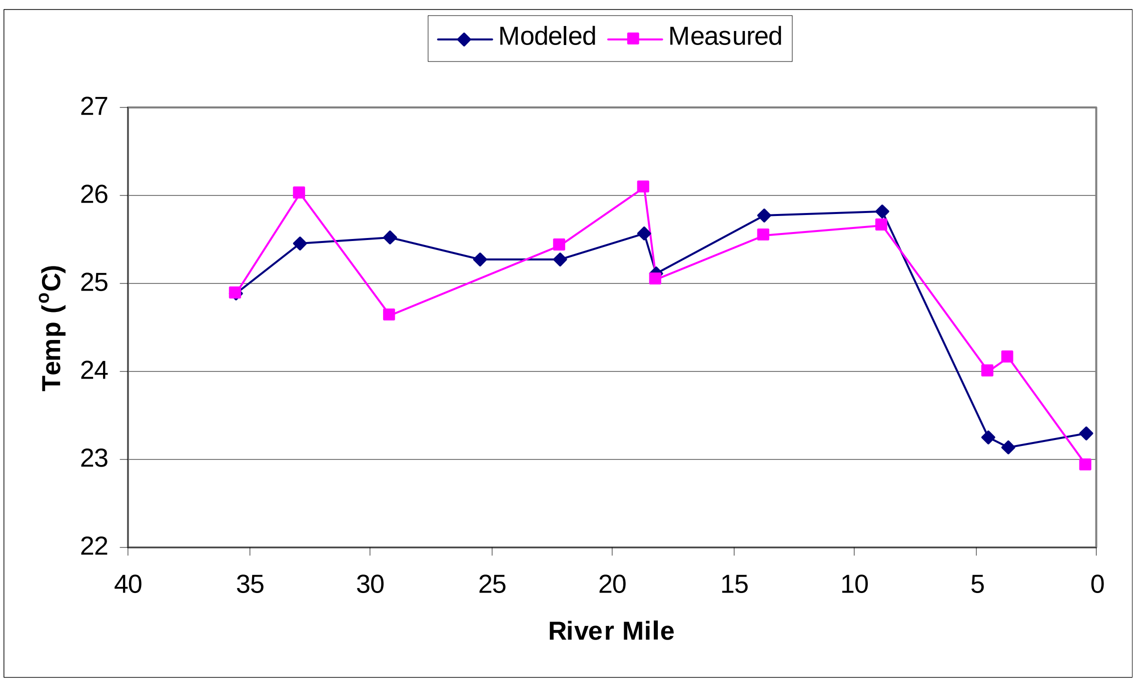


Figure T2. Weekly average stream temperatures measured and modeled at several sites along Hangman Creek for week 28 in July 2002 (Hardin and Davis, 2003).

Groundwater and springs consistently lower water temperatures between river mile 10 and the mouth of the creek. Figure T2 is an example of the trend recorded during the 2002 SNTEMP study. According to instream flow data collected for the study, water volumes double through that 10-mile reach, primarily from groundwater sources. Surface water inputs are minimal.

Marshall Creek is the largest tributary to the reach. During the 2003 – 2004 monitoring period, Marshall Creek flows decreased between the upstream site at McKenzie Road and the confluence with Hangman Creek. We theorized that much of it went subsurface and emerged as springs along Hangman Creek.

The SCCD surveys for the TMDL also documented instantaneous water temperatures greater than 17.5°C in Hangman Creek from the Idaho state line (RM 55) to Duncan Road (RM 18.7), the mouth of Little Hangman Creek, the mouth of Rattler Run Creek, Rock Creek from Rockford to the mouth (SCCD, 2005).

Critical conditions

Existing conditions for stream temperatures in the Hangman Creek watershed reflect seasonal variation. Cooler stream temperatures occur in the winter, while warmer stream temperatures exceeding criteria are observed from late April through summer and into October. The highest temperatures typically occur from mid-July through mid-August (Figure T1). This time frame is used as the critical period for development of most of the TMDL. Critical season adjustments may be necessary later if, for example, cooler temperatures are needed to protect life-stages for sensitive fish species. Point source temperature limits may apply to the entire spring to fall season.

Seasonal estimates for streamflow, solar flux, and climatic variables for the TMDL are taken into account to develop critical conditions for the TMDL model. The critical period for evaluation of solar flux and effective shade was assumed to be August 1 because it is the mid-point of the period when water temperatures are typically at their seasonal peak. The SNTEMP modeling explored increased streamflow and shade, separately and together. The shade modeling, performed as a separate effort, evaluated the effect of additional shade in blocking radiant energy during the critical period.

Analytical framework

The theory and physical laws governing temperature and heat in streams are briefly outlined in Appendix x. Equations based on these concepts have been applied to various tools and models used by scientists to simulate water temperature data. Ecology's scientists calibrate these models to local conditions after collecting information from the stream, the lands surrounding the stream, local weather stations and maps. Then historical, current, and future stream temperatures are simulated to find the best ways to evaluate and protect aquatic organisms against extreme temperature effects.

The temperature TMDL is built from work previously conducted for the Hangman Creek Watershed Planning Unit under the 2514 Watershed Planning process. Hardin-Davis (2003) used data collected by the Spokane County Conservation District (SCCD) for a Stream Network

Temperature (SNTEMP) model. SNTEMP simulates mean daily temperatures along a stream under steady-state flow conditions (USGS, 2006). The model included 34.5 river miles from Hays Road to the mouth of Hangman Creek.

The SNTEMP model results and continuous temperature monitoring were adequate to determine the seasonal and spatial extent of the temperature problem in Hangman Creek. The field data documented that stream temperatures do not meet current water quality criteria all along the mainstem. The SNTEMP modeling demonstrated that average temperatures could not meet criteria with small increases in flow (3 cfs) and an increase in shade from current conditions of 20% to 70% (Hardin-Davis, Inc., 2003). Additional work was necessary to provide TMDL shade targets.

The geographic information system (GIS) and modeling analysis was conducted using two specialized software tools:

- ODEQ's Ttools extension for Arcview (ODEQ, 2001) was used to sample and process GIS data for input to the Shade model.
- Ecology's Shade model (Ecology, 2003a) was used to estimate effective shade along the mainstems of Hangman Creek from the Idaho border to the mouth. Effective shade was calculated at 100-meter intervals along the streams and then averaged over 1000-meter intervals.

All input data for the Shade model are longitudinally referenced, allowing spatial inputs to apply to certain zones or specific river segments. Model input data were determined from available GIS coverages using the Ttools extension for Arcview, or from data collected by the SCCD or other data sources. Detailed spatial data sets were developed for the following parameters for model calibration and confirmation:

- The creek was mapped at 1:3,000 scale from one-foot resolution color Digital Orthophoto Quads (DOQ) of the watershed.
- Riparian vegetation size and density were mapped at 1:3,000 scale from the Digital Orthophoto Quads (DOQ) and sampled from the GIS coverage along the stream at 100-meter intervals along the streams in the study area.
- Effective shade was calculated from vegetation height and density with Ecology's Shade model.
- Near-stream disturbance zone (NSDZ) widths were digitized at 1:3000 scale.
- West, east, and south topographic shade angle calculations out to 9 miles were made from the 10-meter DEM grid using ODEQ's Ttools extension for Arcview.
- Stream elevation was sampled from the 10-meter DEM grid with the Milagrid Arcview extension. Gradient was calculated from USGS 1:24,000 quad maps.
- Aspect (streamflow direction in decimal degrees from north) was calculated by the Ttools extension for Arcview.

Tributaries were not analyzed directly from orthophotos and GIS tools. The tributaries and perennial streams in the Hangman Creek watershed are narrow enough that riparian vegetation shade would usually dominate stream cooling compared to geographic features. Shade curves and a shade table were created from the Shade model vegetation regional analysis. Shade potential for tributaries can be estimated when channel aspect and bankfull width are known.

Calibration of SNTEMP and Shade models

According to Hardin-Davis, Inc. (2003), only minor adjustments were needed in the SNTEMP model to match measured temperatures. The calibration narrative continues:

> 'The wind speed parameter in SNTEMP is the primary calibration tool. When the weekly average wind speed input values were varied from 4 to 16 miles per hour…, the modeled temperatures showed good agreement with measured temperatures during most weeks, and at most sites… The median absolute error was 0.5ºC, and 79% of the errors were less than 1ºC. Root mean squared errors were under 1ºC for most weeks and sites. Given this level of agreement, no further calibration adjustments were made.
>
> Weeks 27 and 33 had the poorest agreement; simulated temperatures were too high by an average of 1.5ºC in week 27, and too low by 0.75ºC in week 33. These results could have been due to discrepancies between conditions at the meteorological station (Spokane Airport) and local conditions. Among the sites, RM 29.2 and Avista Substation Bridge (RM 3.6) had the largest errors. SNTEMP over-predicted temperature at RM 29.2 by an average of 1.05ºC; this may have been because the actual topographic shading effect in the canyon was greater than estimated. The model under-predicted by 0.81ºC at Avista Substation Bridge, probably because groundwater cooling was less than estimated.
>
> Weekly average temperatures at all sites…showed a peak at week 28 (mid-July), and a secondary peak at week 34 (late August). The simulated behavior was consistent with measured values. Longitudinally, the pattern was more complex. Depending on the week, the temperature either increased gradually from RM 35.5 to RM 8.8, or varied erratically. In either case, water temperature was at or near its longitudinal maximum at RM 8.8. Temperature dropped sharply from there to RM 3.6; SNTEMP followed the measured data closely over this distance.
>
> Maximum temperatures (weekly average maxima) measured by SCCD were 1.0º to 5.2ºC greater than weekly averages…The greatest differences were in the upstream portion of the reach, where shade and groundwater are minimal…SNTEMP is designed for best results with average, as opposed to maximum temperatures; thus, no comparisons were made between measured and simulated maxima. The effects of scenarios on temperature maxima were not simulated with SNTEMP.'

The shade model was based on aerial photos and compared to densiometer measurement collected by SCCD field staff (Figure T3). The shade model accounts for topographic shading, so model results were generally higher than densiometer measurements. However, field data and model results were in good agreement where riparian vegetation was the dominant form of shade available.

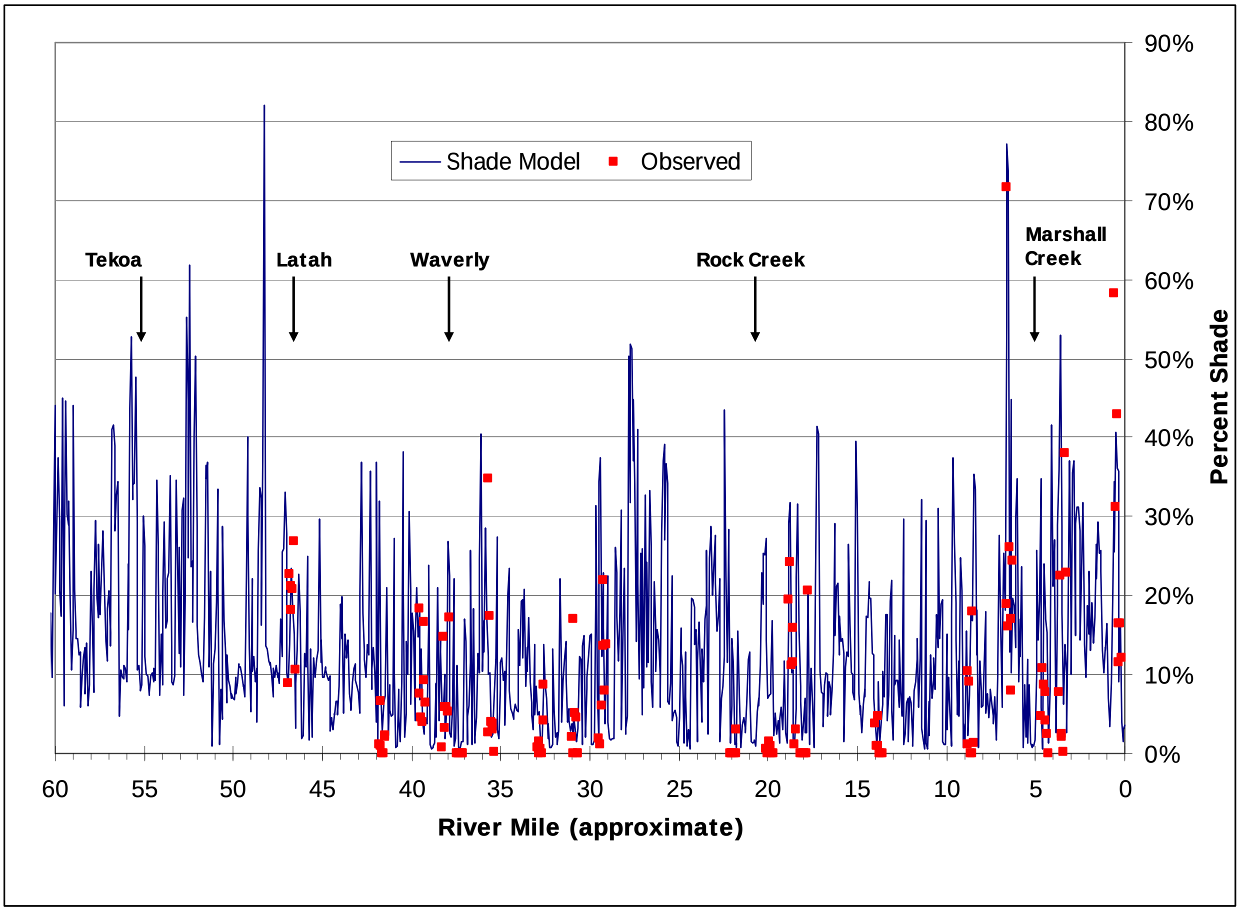


Figure T3. Current shade along Hangman Creek comparing shade model results to canopy closure measurements taken by THE SCCD with densiometer transects at selected locations.

Loading capacity

The loading capacity provides a reference for calculating the amount of pollutant reduction needed to bring water into compliance with standards. EPA's current regulation defines loading capacity as "the greatest amount of loading that a waterbody can receive without violating water quality standards" (40 CFR § 130.2(f)). Water temperature loading capacities in the Hangman Creek watershed are solar radiation heat loads based on potential riparian land cover (primarily vegetation).

The *system potential temperature* is an approximation of the temperature that would occur under natural conditions during specified conditions of air temperature and streamflow. The system potential temperature is estimated using analytical methods and computer simulations proven effective in modeling and predicting stream temperatures in Washington (Baldwin and Stohr, 2007; Cristea and Pelletier, 2005; Pelletier and Bilhimer, 2004). The system potential temperature is based on our best estimates of the *mature riparian vegetation and riparian microclimate* that did not include human modifications.

A system potential temperature is estimated for the summer low-flow *critical condition* of upper 90th percentile air temperatures and low streamflows that occur only once every ten years. The system potential temperature does not, however, replace the numeric criteria, nor invalidate the need to meet the numeric criteria at other times of the year and at other less extreme low flows and warm climatic conditions.

At locations and times where the system potential temperature is warmer than the numeric criteria assigned to the waterbody, or within 0.3ºC of the criteria, the loading capacity and load allocations in this TMDL are to be based on not allowing cumulative human sources to increase the seven-day average daily maximum (7-DADMax) temperature water by more than 0.3°C. The following sections from the state water quality standards apply:

Numeric threshold temperature criteria are established in the state water quality standards [WAC 173-201A-200(1)(c)]. These numeric criteria are designed to ensure specific communities of aquatic life will be fully protected whenever and wherever the numeric criteria are met. The state standards recognize, however, that some waterbodies may not be able to meet the numeric criteria at all places and all times.

WAC 172-201A-200(1)(c)(i) states that: "When a water body's temperature is warmer than the criteria in Table 200(1)(c) (or within 0.3ºC (0.54ºF) of the criteria) and that condition is due to natural conditions, then human actions considered cumulatively may not cause the 7-day average daily maximum (7-DADMax) temperature of that water body to increase more than 0.3ºC (0.54ºF).

The air temperatures used to evaluate statewide critical conditions are referenced to average July and August temperatures in 1997 (as an average flow year) and 1998 (as a low-flow year) (Stohr, 2007). The 2002 July and August air temperatures in Spokane were not too dissimilar from these reference conditions (Table T3). The 2002 temperatures were slightly warmer in June and July than in 1997, but not as warm as in 1998. However, monthly discharges in the creek were much lower in 2002 than in 1997 or 1998 (Table HC1). Therefore, it's likely the 1997, 1998, and 2002 conditions in Hangman Creek were comparably critical in terms of water temperature because of the lower flow volumes available in 2002 to buffer solar heating.

Table T3. The average monthly air temperature in degrees centigrade reported at the Spokane Airport for the months of June through September in 1997 through 2004.

	Jun	Jul	Aug	Sep
1997	15.52	19.75	21.63	16.59
1998	16.94	24.03	22.03	18.38
1999	15.51	18.98	21.27	15.07
2000	16.10	19.90	19.75	13.21
2001	14.82	20.22	21.70	17.37
2002	16.82	21.84	19.12	14.71
2003	17.56	22.77	21.26	16.61
2004	17.56	22.35	21.66	14.44

Hardin-Davis Inc. (2003) noted that the water temperature conditions in the creek were a result of inadequate channel shading and low seasonal discharge volumes with very little groundwater interaction. They also noted that average temperatures observed and modeled in the creek exceeded recommended guidelines for trout survival, and could not be brought within guidelines with 70% riparian shade on all reaches and a net 3 cfs flow increase. Stream channel restoration activities were not assessed.

Ecology further analyzed the effects of shade to determine the system potential and to calculate the loading capacity. Instead of applying a single 70% shading factor to all reaches, an evaluation of landscape and vegetation shading effects on the creek was conducted. Channel width and aspect were considered in the evaluation.

Washington Department of Natural Resources, Natural Resources Conservation Service, and Spokane County Conservation District data provided historical and soil potential vegetation heights. The potential maximum vegetation height had a range of 71 – 102 feet. Based on field observations and historical data, a two-layered, 100-foot riparian zone was simulated:

1. A 35 foot zone of 30 foot willows and alders with a 75% density next to the banks.
2. A pine forest located another 65 feet out with tree heights of 80 feet and a 50% density.

This is a generalized scheme of the potential mature riparian vegetation that would be present in much of the watershed. A different set of riparian vegetation metrics may be more appropriate at individual sites as restoration occurs, especially in the Columbia Plateau Ecoregion areas. The riparian areas of Columbia Plateau Ecoregion may not be able to support the pine forest, and tree heights may be shorter. Channel restoration also can influence the outcome of shade efficiencies from riparian vegetation and needs to be considered for maximum thermal reduction.

The Hangman Creek mainstem model results for system potential shade compared to the current shade conditions are graphically displayed in Figure T3. The amount of solar radiation gained in terms of watts per square meter (W/m^2) along the creek under the two conditions is also displayed in Figure T4. Notice how potential riparian shading is enhanced by the east to west orientation of the creek near Tekoa, and by the canyon features at RM 22 to RM 28. The average difference in current and system potential shade was 26% with the greatest need for additional shade in the upper 18 miles of the watershed and near the mouth.

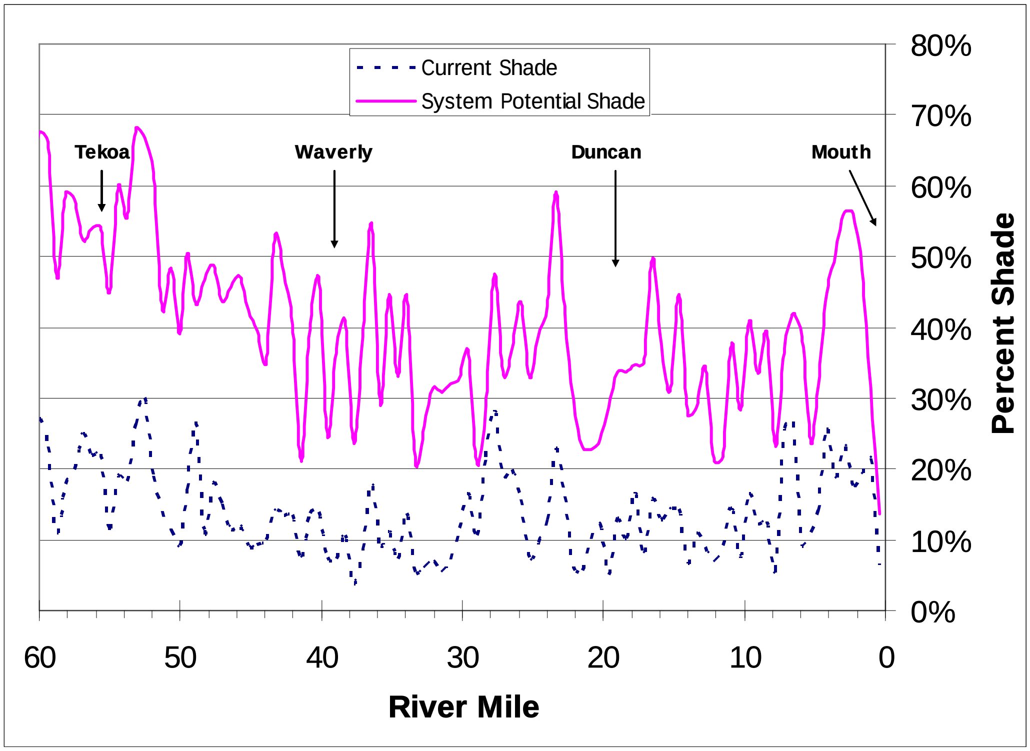


Figure T3. Current conditions and system potential shade estimates (1000 meter averages) along Hangman Creek based on the shade model.

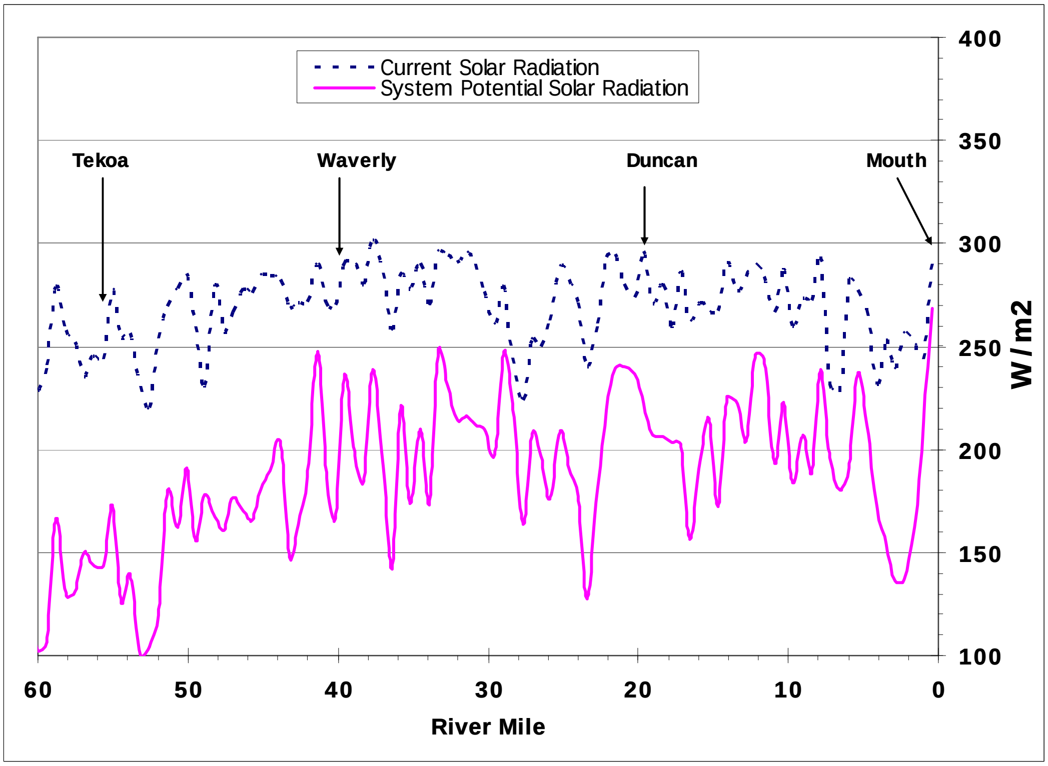


Figure T4. System potential thermal loads along Hangman Creek compared to loads under current conditions based on shade and aspect inputs to the Shade model. Thermal loads are in terms of watts per square meter (W/m^2).

Load and wasteload allocations

Load allocations (for nonpoint sources) and wasteload allocations (for point sources) are established in this TMDL to meet both the numeric threshold criteria, and the allowances for human warming under conditions that are naturally warmer than those criteria.

Since Hardin-Davis (2003) demonstrated that system potential water temperatures in most of Hangman Creek would not meet numerical water quality standards during the hottest period of the year, there is a need to achieve maximum protection from direct solar radiation. The load allocations are then based on effective shade from maximum system potential mature riparian vegetation, i.e. that vegetation which can grow and reproduce on a site given climate, elevation, soil properties, plant biology and hydrological processes. The load allocations, in terms of heat and effective shade, for the mainstem of Hangman Creek are quantified in Appendix _, Table X.

Table T4 provides the heat load allocation and required vegetation shading terms for individual sites along Hangman Creek on the 2004 303(d) list and those proposed for the 2006/2008 303(d) list. Tributaries are also listed in the table. These were not directly modeled, so they require a different approach. The application of a shade curve based on the system potential shade used in the Shade model for the mainstem Hangman Creek is proposed as a load allocation mechanism.

For all tributaries and perennial streams in the watershed with temperature criteria violations, the load allocations for shade can be applied from Figure T5 and Table x, Appendix D based on the estimated relationship between shade, channel width, and stream aspect at the assumed maximum riparian vegetation condition used in the Hangman Creek mainstem Shade model. Perennial streams include those that would naturally have flow year round but are dry part of some years due to drought.

Most tributary and perennial stream channels in the Hangman Creek watershed, including those in Table T4, are narrow enough to be influenced more by vegetation shade than by landscape shade. As metrics are collected for sites in these areas, site potential effective shade can be assigned as a load allocation from Figure T5 and the accompanying Table x, Appendix X. The assigned load allocations are expected to result in water temperatures that are equivalent to the temperatures that would occur under natural conditions. Therefore, the load allocations are expected to meet the water quality standard.

Table T4. Heat load allocations and shade requirements for 2004 and 2006/2008 303(d) listed sites in the Hangman Creek watershed based on the Shade model results. Heat is measured in watts per square meter (W/m^2). Tributary values need to have site specific metric collection and application of the shade curve in Figure T5.

Water Body	Listing ID	Section, Township, Range	Location	W/m^2	Shade Required
Rattler Run	48303	Section 16 T22N R44E	Rattler Run at Mouth	Shade curve	Shade curve
Rock Creek	48333	Section 12 T23N R43E	Rock Creek Mouth	Shade curve	Shade curve
California Creek	48340	Section 03 T23N R43E	Calif. Creek mouth	Shade curve	Shade curve
Marshall Creek	48368	Section 31 T25N R43E	Marshall Cr. mouth	Shade curve	Shade curve
Hangman Creek	48370	Section 36 T25N R42E	River Mile 3.6	172	45%
Hangman Creek	48371	Section 31 T25N R43E	Above Marshall Cr.	212	32%
Hangman Creek	48372	Section 28 T24N R43E	HangmanValley Golf	225	28%
Hangman Creek	48373	Section 33 T24N R43E	River Mile 18.2	206	34%
Hangman Creek	48374	Section 11 T23N R43E	Duncan Road	207	34%
Hangman Creek	48375	Section 13 T23N R43E	Latah Road	181	42%
Hangman Creek	48376	Section 08 T22N R44E	Keevy Road	198	37%
Hangman Creek	48377	Section 16 T22N R44E	Bradshaw Road	247	21%
Hangman Creek	48378	Section 28 T22N R44E	Hays Road	222	29%
Hangman Creek	48379	Section 01 T21N R44E	Roberts Road	187	40%
Hangman Creek	48380	Section 30 T21N R45E	Spring Valley Road	165	47%
Hangman Creek	48381	Section 09 T20N R45E	Fairbanks Road	162	48%
Hangman Creek	48382	Section 24 T20N R45E	Above Tekoa WWTP	126	60%

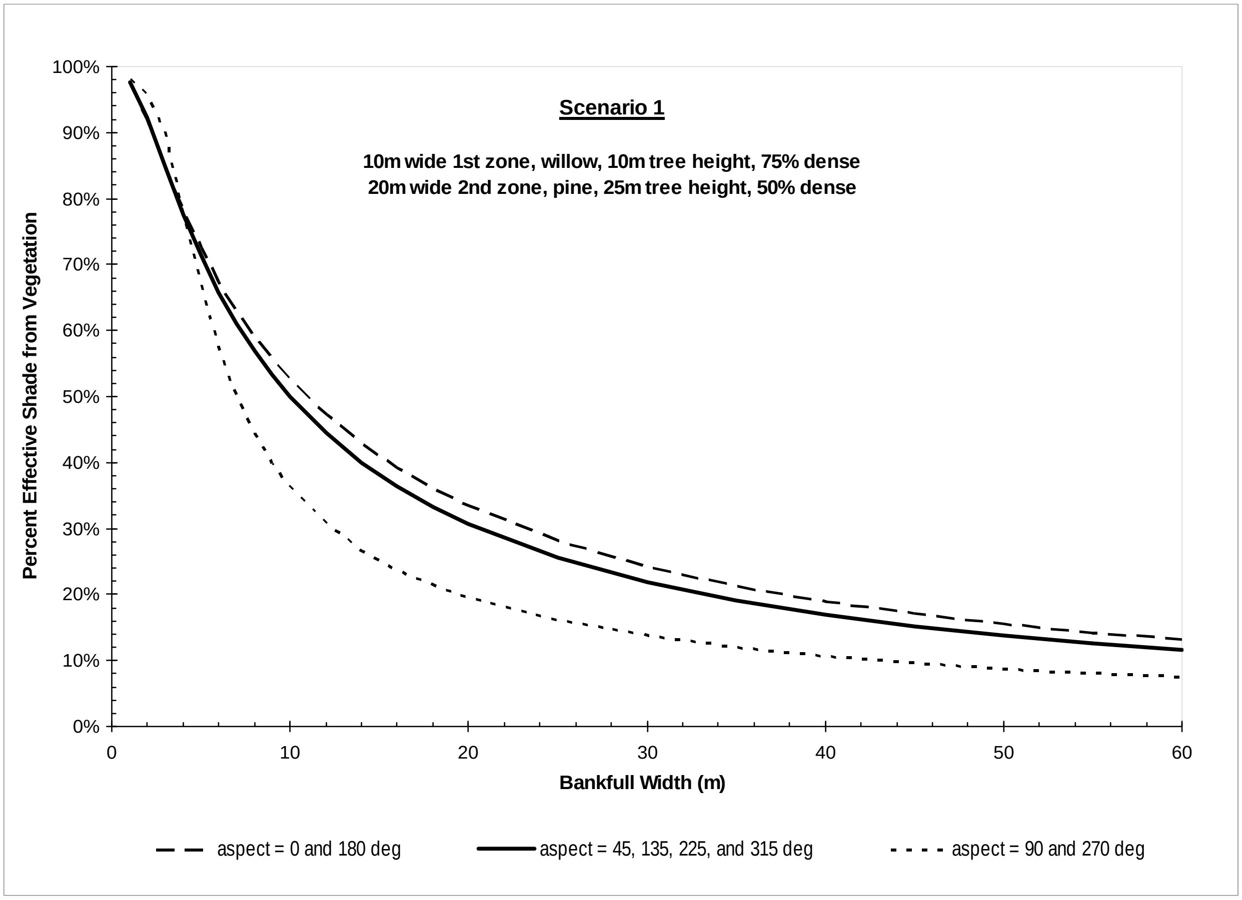


Figure T5. Shade curve constructed for sites in the Hangman Creek watershed based on system potential vegetation maximum heights and stream orientation (aspect) to sunlight in August.

The water quality standards allow an increase over natural conditions for the point sources for establishment of the wasteload allocations. However, point sources must still be regulated to meet the incremental warming restrictions established in the standards to protect cool water periods. This is especially important in the late spring and early fall when stream temperatures may be lower than effluent temperatures but streamflows are low.

Because water temperatures can exceed 17.5ºC on a 7-day average daily maximum in areas of the watershed from late-April through October, all point sources require temperature wasteload allocations. Unfortunately, few of the six wastewater treatment plants have monitored temperature, and nothing is known about stormwater temperatures. Effluent temperature limits will need to be included in all NPDES permits as wasteload allocations

The water quality standards (WAC 173-201A) restrict the amount of warming that point sources can cause when temperatures are cooler than the 17.5°C criteria in Hangman Creek waters:

Incremental temperature increases resulting from point source activities shall not, at any time, exceed t=28/(T+7). For purposes hereof "t" represents the maximum permissible temperature increase measured at a mixing zone boundary; and T represents the background temperature as *measured at a point or points unaffected by the discharge and representative of the highest ambient water temperature in the vicinity of the discharge. When the streamflows allow adequate mixing, maximum effluent plume temperatures cannot be greater than 33ºC to avoid creating areas in the mixing zone that would cause instantaneous lethality to fish and other aquatic life exposed for more than two seconds.*

When the 7-day average daily maximum (7DADM) stream temperatures upstream of the WWTP outfalls are less than 17.5°C, the incremental temperature increase formula noted above defines the allowable temperature increase in the receiving water. As stream temperatures approach 17.5°C, the temperature at the edge of the mixing zone equals the 17.5°C criteria, so any additional warming from effluent would be a violation of criteria. At that time the allowable 7DADM effluent temperature approaches the criteria temperature with an allowance for the dilution factor.

At times and locations where the 7DADM stream temperature is warmer than the assigned numeric criteria even under natural conditions, the state standards hold human warming to a cumulative allowance for additional warming to 0.3°C. The formula used for point sources in these circumstances is based on the dilution factor at the edge of the chronic toxicity mixing zone (Hicks, 2007). For example, the 7DADM temperature for the Tekoa WWTP NPDES effluent (T_{NPDES}) discharge to Hangman Creek is calculated from the following mass balance equation, in recognition that the system potential temperature is greater than 17.5ºC:

T_{NPDES} = [17.5 ºC-0.3ºC] + [(chronic dilution factor = 1.2) x 0.3 ºC]
T_{NPDES} = 17.6 ºC

The allowable 7DADM effluent temperature under these conditions essentially will be at the criteria temperature of 17.5 ºC and allow no incremental increase in receiving waters. This is the WLA temperature for the facilities with low or no dilution factors at:

- Tekoa WWTP (Hangman Creek)
- Fairfield (Rattler Run),
- Spangle (Spangle Creek), and
- Freeman School District (Little Cottonwood Creek)

At higher instream temperature, no incremental increase would be allowed.

The Cheney facility rarely discharges, but currently has a maximum summer temperature permit limit of 20 ºC and a mean of 14.2 ºC. These permit limits may be adequate if effluent does not increase the 7DADM Minnie Creek temperatures above 17.5 ºC.

When 7DADM temperatures reach the 17.5ºC criteria, Rockford WWTP effluent can reach a 7DADM of 18.25 ºC because the facility is only allowed to discharge when a dilution factor of 3.5 is available in Rock Creek.

The recommended effluent temperature limits will create some difficulties for some of the facilities in the Hangman Creek watershed. All of the WWTP facilities should monitor receiving water and effluent temperatures and discharge volumes during the spring through fall season.

When the thermal and dilution cycles are better understood, compliance schedules and operational/facility options can be better designed.

Spokane County, the City of Spokane and Washington State Department of Transportation (WSDOT) have Phase 2 municipal stormwater permits. The most critical season (July and August) rarely has storm events of enough intensity and duration to generate significant municipal stormwater that would increase stream temperatures over a 7-day period. However, the late April through October season when Hangman Creek stream temperatures exceed criteria may be susceptible to stormwater effects. Data are not available to assess these impacts, but permit holders need to evaluate their systems for potential stormwater thermal effects.

Conclusions and recommendations

The following conclusions and recommendations are based on this temperature TMDL evaluation:

- Many reaches of Hangman Creek and its tributaries cannot meet the 17.5ºC temperature criterion during the summer low-flow period.
- Groundwater and springs plays an important cooling role in the lower 10 miles of Hangman Creek below its confluence with Marshall Creek.
- A buffer of mature riparian vegetation along the banks of the creek and its tributaries is expected to decrease instream average daily maximum temperatures to natural levels.
- Site specific metrics of channel width and aspect will be necessary to apply the shade curve load allocations to tributaries and perennial streams.
- Channel restoration measures should be implemented to reduce heat loads on the stream and encourage riparian vegetation growth.
- Wastewater treatment plant effluent 7DADM temperatures for facilities in Tekoa, Spangle, Fairfield, and Freeman School District should be limited to instream temperatures when the 7DADMs are greater than 17.5 ºC. WWTP facilities should monitor receiving water and effluent temperatures and discharge volumes during the spring through fall season to understand thermal and dilution cycles better so that compliance schedules and operational/facility options can be designed.
- Spokane County, the City of Spokane and Washington State Department of Transportation (WSDOT) Phase 2 municipal stormwater thermal effects are not expected to impact Hangman Creek, but permit holders should evaluate their systems to prevent them.

Allocation for future growth

Hangman Creek watershed primarily has an agricultural land base. Conversions of agricultural land to residential or non-commercial farms are of concern in the watershed. These conversions are expected to occur in lower catchments of the watershed. Requirements for riparian shade and channel improvements recommended by this TMDL will remain the same as land is converted, so no additional allocation for future growth is necessary. No other point sources are anticipated in the next five to ten years. Stormwater effects will be controlled through county, city and state stormwater permits.

Margin of safety

The federal Clean Water Act requires that Total Maximum Daily Loads (TMDLs) be established with margins of safety (MOS). The MOS account for uncertainty in the available data, or the unknown effectiveness of the water quality controls that are put in place. The MOS can be stated explicitly (e.g., a portion of the load capacity is set aside specifically for the MOS). But, implicit expressions of the MOS are also allowed such as conservative assumptions in the use of data, application of models, and the effectiveness of proposed management practices.

Implicit MOS elements were applied to analyses to provide some MOS for Hangman Creek temperature TMDL evaluation. The temperature TMDL requires shading and long-term implementation of riparian and channel improvements that take several years. The heat reductions and allocations are conservatively set to aquatic community health and beneficial uses to the fullest extent. The following are conservative assumptions that contribute to the MOS:

- Data were collected under conditions equivalent to 7-day average flows during July-August with recurrence intervals of 10 years (7Q10). Allocations are set to protect stream temperatures under reasonable worst-case conditions.
- The load allocations are set to the effective shade provided by full mature riparian shade, which are the maximum values achievable in the Hangman Creek watershed. The riparian vegetation scheme applied to Hangman Creek is conservative in that some riparian areas in the Columbia Plateau Ecoregion may not be able to support vegetation heights assigned.
- The load allocations and calculations for the temperature TMDL are based on protecting salmonid species that are not known to be currently present. Protective measures to meet these more restrictive criteria may allow potential re-establishment of some absent species.

Total phosphorus

Areas of concern

Phosphorus concentrations have been monitored by Ecology at the mouth of Hangman Creek on a monthly basis for several years (Figure P1). The total phosphorus (TP) concentrations are highly correlated with discharge volumes. Figure P2 shows that both TP and orthophosphate phosphorus (OPO_4-P) concentrations at the site have declining trends over the past 10 years (1995 – 2005). The declining trend is similar to the trend in discharge (Figure FC2) and total suspended solids (Figure P3).

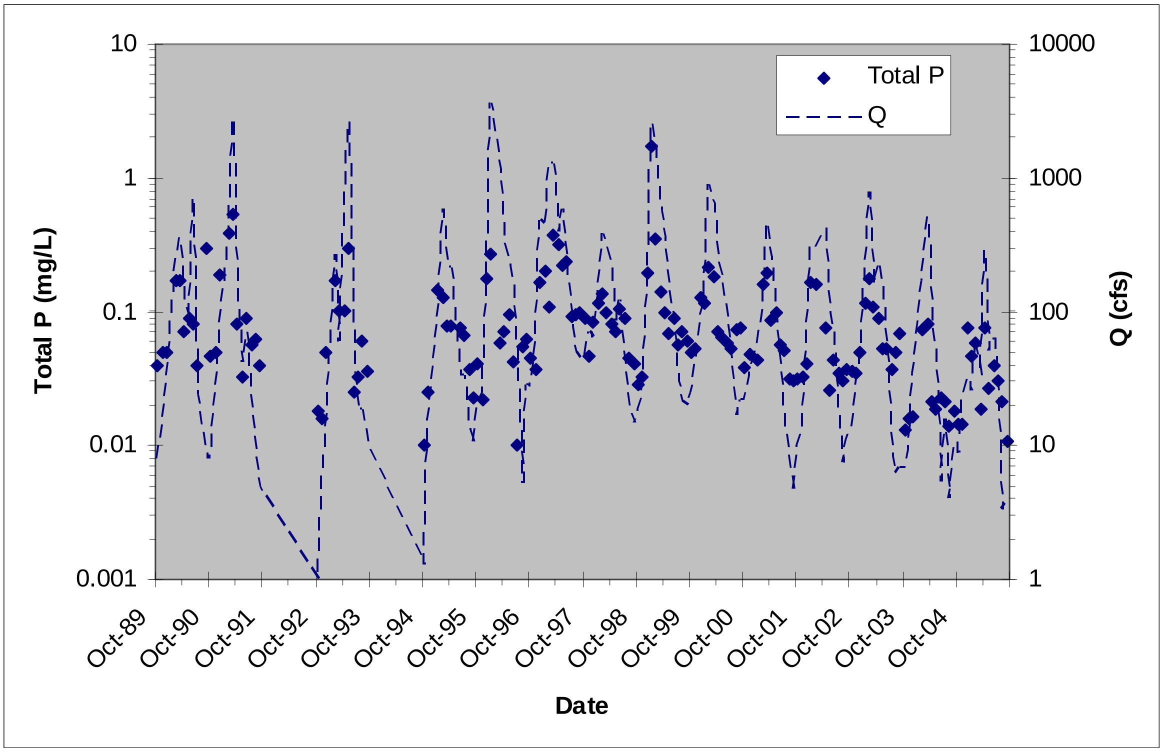


Figure P1. Total phosphorus (Total P) and discharge (Q) reported from monthly observations at the mouth of Hangman Creek (Ecology 56A070).

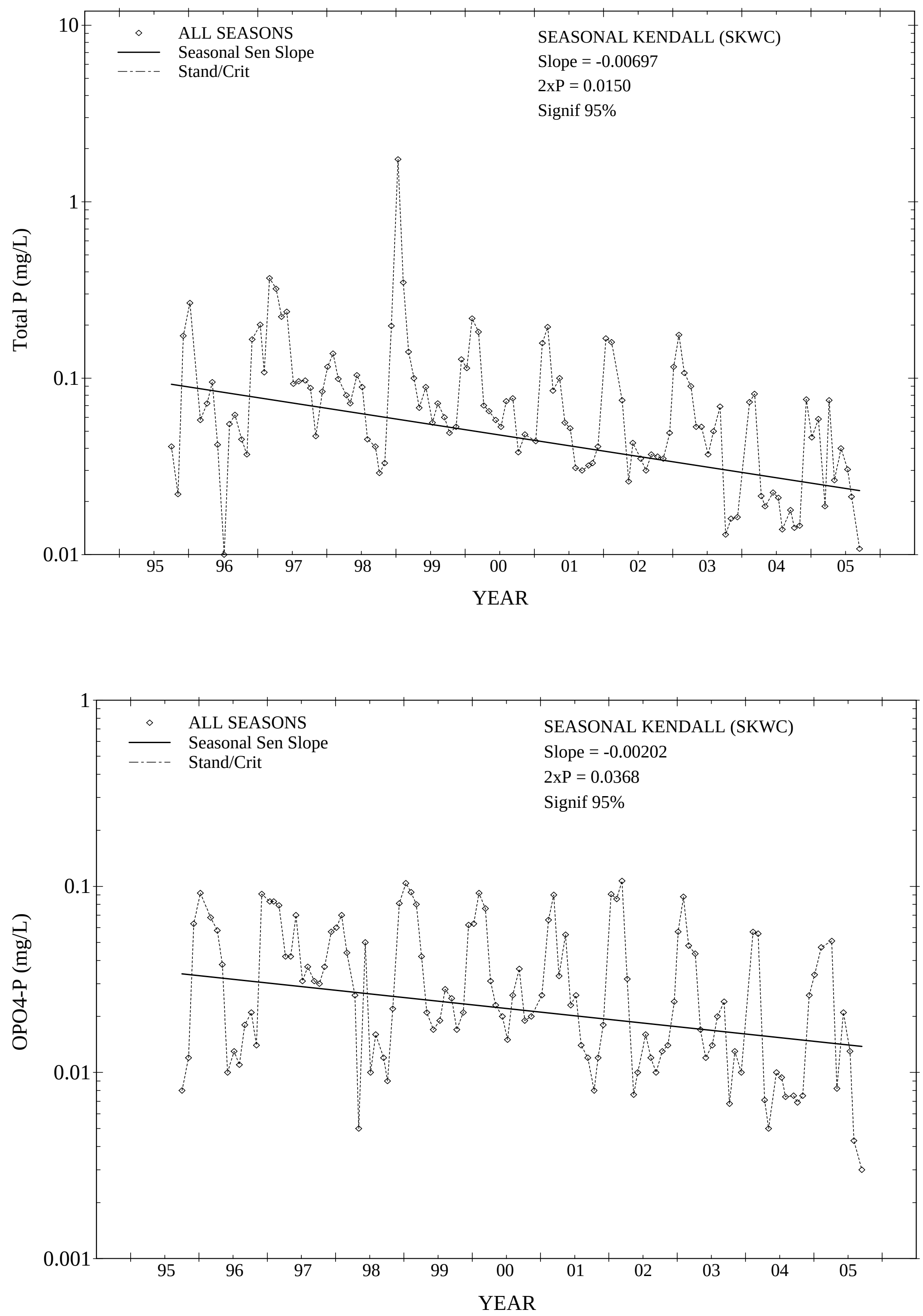


Figure P2. Total phosphorus (Total P) and orthophosphate phosphorus (OPO4-P) trends from 1995 – 2005 from monthly samples in Hangman Creek at Ecology station 05A070.

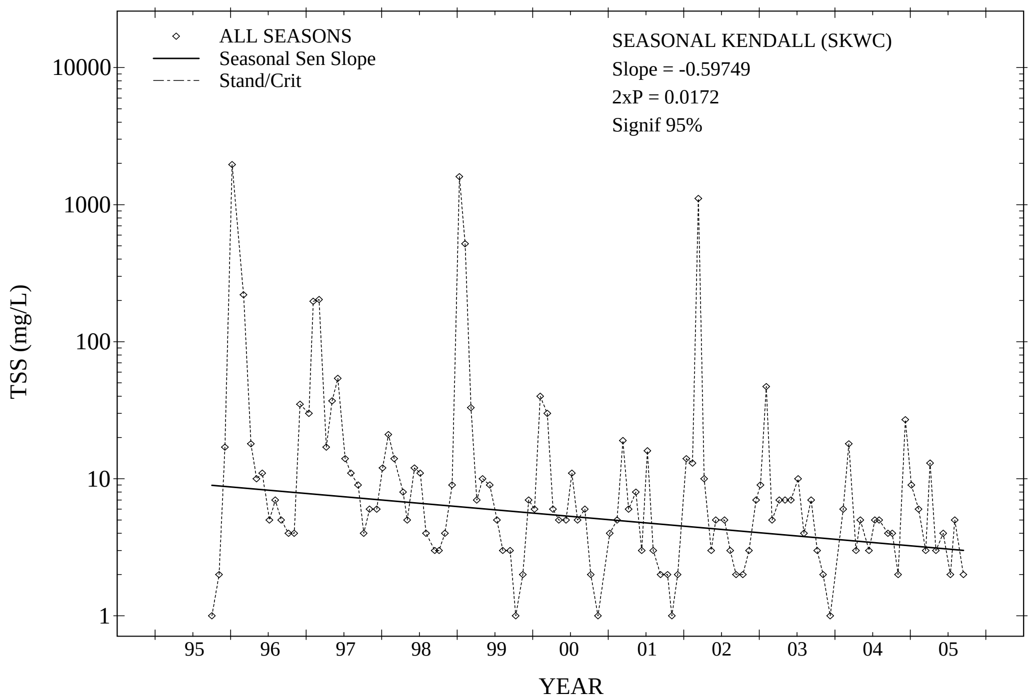


Figure P3. The total suspended solids (TSS) trend from 1995 – 2005 from monthly samples in Hangman Creek at Ecology station 05A070.

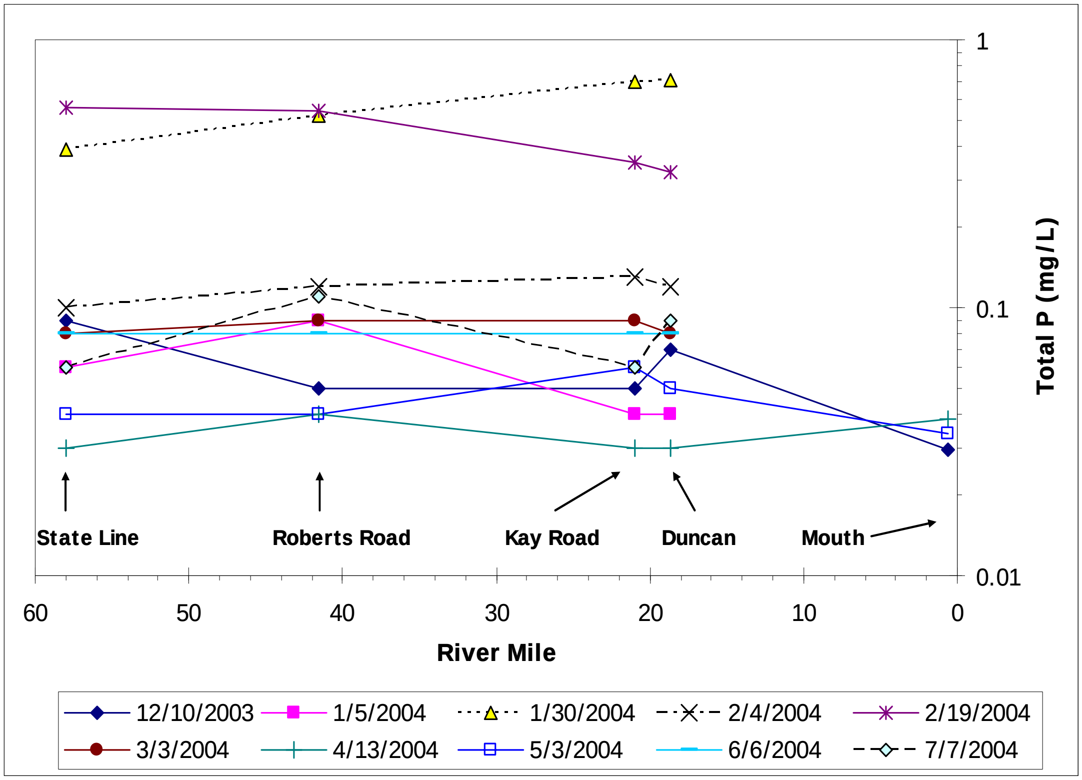
As described earlier, the Spokane River TMDL study to restore dissolved oxygen (DO) concentrations in Long/Spokane Lake recommended seasonal phosphorus limits for Hangman Creek (Ecology, 2007). April through October load allocations of phosphorus, nitrogen, and carbonaceous biochemical oxygen demand (CBOD) were based on 2001 critical conditions (a low-flow year) to determine necessary reductions to meet the DO target. Hangman Creek was considered an important loading source to the river especially from April through June.

Hangman Creek also has documented pH and DO criteria violations in several areas within the watershed that may be associated with excessive phosphorus (Table 3 – Page 15). However, they have not been investigated to the point of determining if phosphorus or nitrogen is the limiting nutrient, or if light and temperature are more significant factors controlling eutrophication processes. Future studies may examine these areas in more detail.

Figure P4 shows the 2004 profile of TP concentrations and loads along Hangman Creek from the Idaho state line to Duncan collected by the SCCD (2005). Data from the Ecology site at the mouth (56A070) are included for three events when sampling coincided. Most of the TP concentrations above the mouth were in the range of 0.03 mg/L to 0.30 mg/L, but the concentrations at the mouth were usually 0.03 mg/L to 0.12 mg/L. Phosphorus loads were sometimes lower at the mouth than upstream. The lowest concentrations occurred during the growing season (April – July in this dataset).

The SCCD (2005) monitoring study demonstrated that tributaries contribute significant TP loads to Hangman Creek. The TP concentrations in the bed and streambank sediments of the tributaries are one potential source. In 2007, the SCCD collected soil and sediment samples to examine TP concentrations in various regions and soil types. The TP sampling showed some regional variability (unpublished data, personal communication Rick Noll, SCCD, 2007). Rock Creek, California Creek, Marshall Creek, and Stevens Creek in the northern part of the watershed tend to have slightly lower average TP concentrations than sub-basins in the Columbia Plateau Ecoregion such as Spangle Creek, Cove Creek, Rattler Run, and Little Hangman Creek. This may be due to underlying geology and soils, land uses, or other factors.

Many of the water problems identified in this TMDL report require actions that will reduce eutrophication potential within Hangman Creek. Future nutrient controls to limit human-caused eutrophication in parts of the watershed may be necessary after efforts at riparian shading, blocking light and lowering temperatures, are achieved. This type of nutrient limiting effort could target the summer low-flow critical season or the entire year. It would depend on the sources of nutrients being used by the plant communities. It could also vary by location within the watershed.



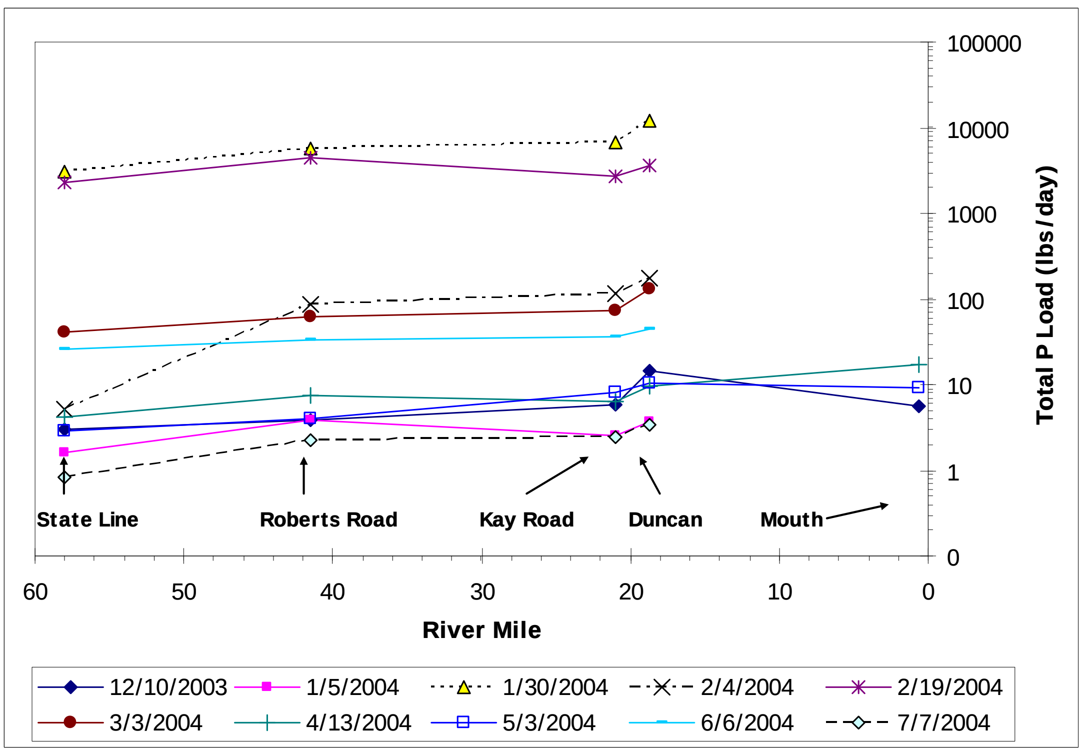


Figure P4. Total phosphorus (Total P) concentrations and loads based on grab samples collected at various sites along Hangman Creek in 2004 (SCCD, 2005; Ecology, 2006).

Critical conditions

Total phosphorus (TP) loads from Hangman Creek affect the Lake Spokane dissolved oxygen (DO) problem (Ecology, 2007). This TMDL assessment is focused on the TP load from Hangman Creek to the Spokane River. As just mentioned, phosphorus loads also may be a significant source for some of the DO and pH problems within the Hangman watershed during low-flows. A future assessment may be planned to address the role of phosphorus in watershed DO and pH violations. Results of those assessments may require more stringent phosphorus controls than are necessary to meet the Spokane River Dissolved Oxygen TMDL load allocations.

Hangman Creek total phosphorus loads of greatest concern to the Spokane River are generated in the spring; summer loads are minor additions. As mentioned earlier, the Spokane River Dissolved Oxygen TMDL has recommended load allocations to Hangman Creek for the months of *April through October*. The months of *April, May and June are the most critical* in terms of phosphorus discharge from Hangman Creek affecting the Spokane River.

The spring phosphorus loads are generated by relatively short duration events. Hangman Creek has a very 'flashy' hydrograph during the spring when compared to the nearby Little Spokane River (Figure P5). The flashiness is an important characteristic that influences sediment and phosphorus transport from the watershed and along the stream channel. Therefore, phosphorus concentrations are significantly correlated with streamflow (Figure P1) and sediment concentrations (Figure P6) in Hangman Creek.

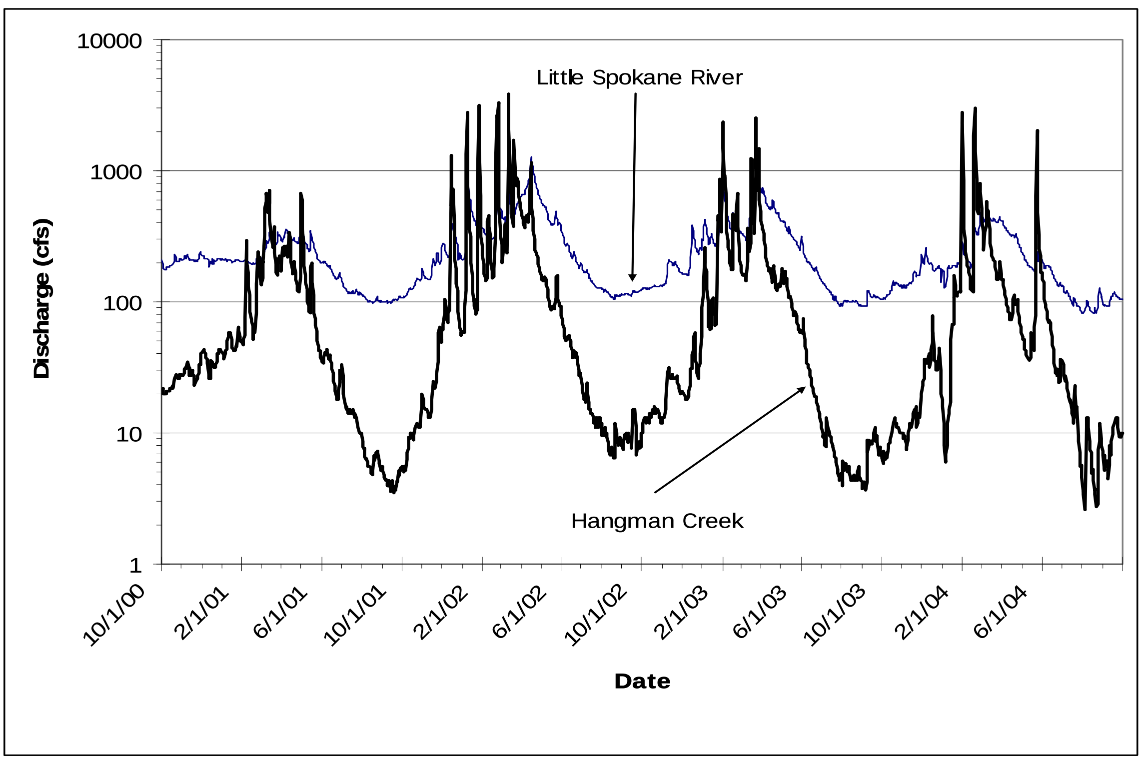


Figure P5. Discharge records for the Little Spokane River (USGS 12431500) compared to Hangman Creek (USGS 12434000) from October 2000 to October 2004.

Hangman Creek's April to June TP loads are the highest for the Spokane River and Lake Spokane. However, phosphorus loads generated by sources in the watershed do not necessarily reach the Spokane River immediately. Phosphorus generated in upper Hangman Creek in Idaho may take years to reach the Spokane River because of long periods of settling in intervening channels until a scour event of high enough intensity and duration can move it downstream. Some phosphorus is taken-up into the aquatic community as plant and animal life with varying life spans. So, an all season, multiple-year TP loading assessment is necessary to address the critical period loading.

Phosphorus is highly associated with suspended sediment and detrital materials in the Hangman Creek watershed (Figure P6). Phosphorus compounds adsorb to sediment and are an essential element of organic particles that are carried in the water column. Water column sediments are generated from upland land sources, from eroded streambanks, or resuspended from bed sediments. Rapidly melting snow or heavy rainstorms drive loam, clay, and silt soils into the creek. Quickly rising and turbulent water in the creek channel erode unprotected streambanks. Decaying plant material and phosphorus in bed sediments are carried along as higher flows scour the stream channel.

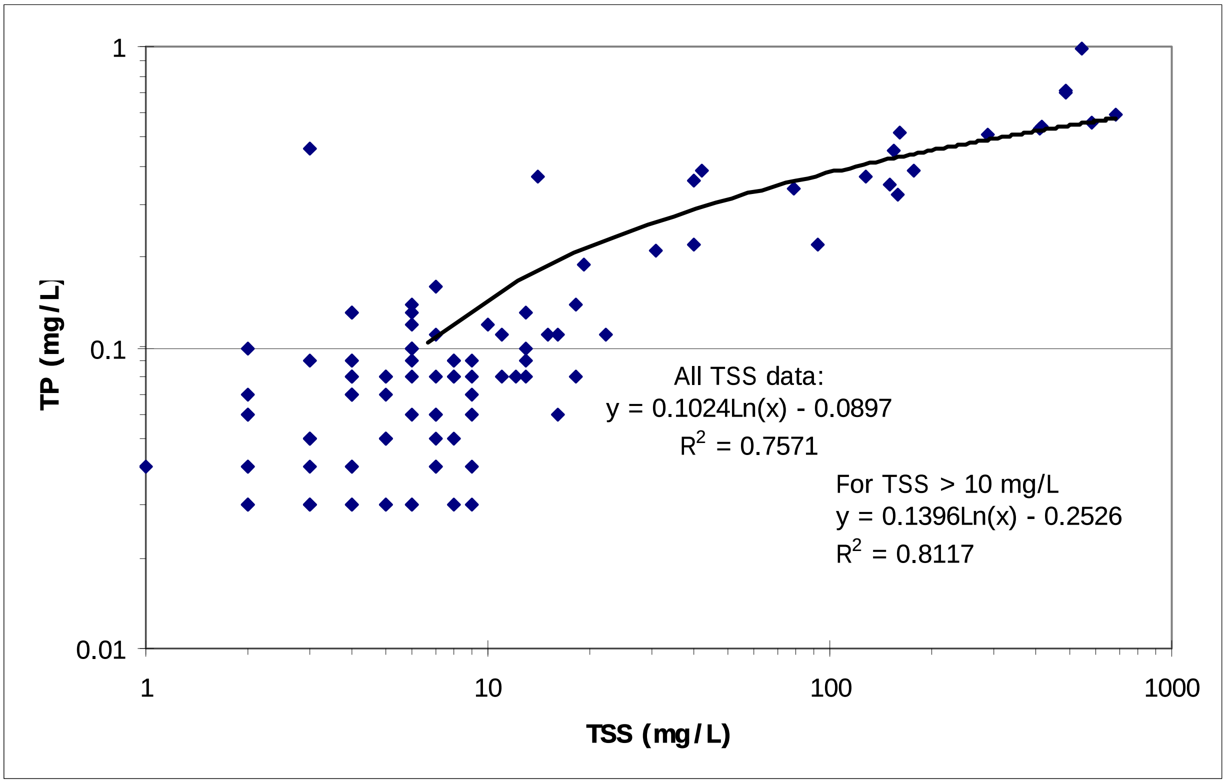


Figure P6. The relationship between total suspended solids (TSS) and total phosphorus (TP) for all samples collected from Hangman Creek by the Spokane County Conservation District

December 2003 to July 2004. The correlation coefficient (R^2) and regression equations for all samples and when TSS samples were greater than 10 mg/L are shown.

Although detailed biological and chemical data are not available at this time to calculate nutrient limits to prevent eutrophication in Hangman Creek during low-flow critical conditions, TP reductions in Hangman Creek to comply with Spokane River Dissolved Oxygen TMDL should help alleviate some of the watershed's eutrophication problems. The other TMDLs in this report will assist in this effort as well. The temperature TMDL actions to increase riparian shade will reduce light to the stream and suppress excessive plant growth. Increased riparian vegetation should stabilize streambanks and filter upland TP transport. The fecal coliform TMDL actions will reduce bacteria sources that are also potential sources of excessive nutrients.

Analytical framework

Data collected by Ecology, SCCD, USGS, and the Coeur d'Alene Tribe were used to evaluate the relationships between streamflow, total phosphorus, total suspended solids, and turbidity in Hangman Creek. Total phosphorus correlation with flow and instream particulates is influenced by season. This would be expected for two reasons:

1. Phosphorus is often associated with sediment and organic particles in the water that are transported at greater rates during higher flows and periods of run-off.
2. Phosphorus is a nutrient used more during some seasons than in others by plants, algae, and other aquatic and terrestrial organisms.

These attributes lend themselves to various statistical and mechanistic models where phosphorus concentrations and loads can be estimated, although not usually to a great degree of accuracy.

Several tools were used to examine the phosphorus data from the Hangman Creek watershed to evaluate different parts of the problem and to compare outcomes in the same area. Statistical tests were run using WQHYDRO® (Aroner, 2007) and Microsoft® Office Excel (2003) software. A multiple regression analyses method by Cohn (1988) was used with SYSTAT® software. The Watershed Analysis Risk Management Framework (WARMF) model was run with software provided through the USEPA Office of Environmental Research and originally developed by the Systech Corporation (Systech, 2001).

The multiple regression model and the WARMF landscape model output are not meant to completely match, but are meant to be complementary. The Cohn (1988) multiple regression model is a statistical tool that is only appropriate where continuous streamflow and a fairly large water quality dataset exists such as at the mouth of Hangman Creek. WARMF relies on soil, land use, climate, and land cover data to simulate processes in the watershed that effect TP and TSS generation and transport. It provides a relative estimate of TP and TSS sources loading in catchments that contribute loads to various portions of the creek and cumulatively to the mouth.

Cohn's (1988) log-linear multiple regression model can accurately simulate most of the seasonal variability in the long-term total phosphorus (TP) and total suspended sediment (TSS) loads at the mouth of Hangman Creek. The model provides daily estimates of TP and TSS based on the relationship between daily average discharge data (USGS) and monthly TP and TSS samples (Ecology). The regression model requires estimates of several parameters: a constant, a linear and quadratic fit to the log of discharge, and sinusoidal functions to remove the effect of seasons. More details on the model are provided in Appendix X.

The WARMF model was used to evaluate the relative impact of landscape and water column TP and TSS loads in the entire Hangman Creek watershed (Washington, Coeur d'Alene Reservation, and Idaho). The USEPA Region 10 office provided a grant to perform the work. The USEPA, Coeur d'Alene Tribe, Ecology, and SCCD agreed that an assessment of the whole watershed was necessary. The model was constructed and initially calibrated for the Hangman Creek watershed by the Cadmus Group and CDM (2007).

CDM (2007) divided the watershed into 36 catchments in the model to characterize hydrology and pollutant delivery (Figure P7). Local soils, land uses, climate, and geographic features of the land and stream channels are generalized within each of the 36 catchments of the WARMF model. The average size of the catchments was 12,000 acres with a range of 576 acres to 27,785 acres. Model outputs are calculated daily based on rainfall, temperature, and point source inputs. Descriptions of the model and coefficients of interest are provided in Appendix X.

While working on the WARMF model it became apparent to Ecology and the Advisory Committee that not all TP mechanisms of generation and transport are adequately described in local datasets. Aquatic biomass estimates, soil phosphorus concentrations, septic system failure rates, air deposition concentrations, and streambank erosion rates all require more investigation and analysis. In 2007, the SCCD collected sediment and soil samples for phosphorus analysis from streambanks and uplands to provide some local data (unpublished data, personal communication with Rick Noll, SCCD). This type of basic data collection should be continued to better calibrate WARMF or any future landscape model.

Calibration of the Multiple Regression and WARMF Models

The long-term monthly TP data record collected by Ecology at the mouth of Hangman Creek (Station 56A070) provides a calibration dataset for the Hangman Creek models. However, the dataset has some limitations:

- Samples collected by Ecology at the site are not laterally or transversely integrated, so they may under-represent the true average TP concentration and load under some circumstances (Hallock, 2005).
- It does not record rapid changes in discharge and TP concentrations within a day.
- It has been affected by changes in TP analytical techniques.
- Watershed land uses, and crop rotation and management patterns have changed. So, consistent statistical relationships between season, streamflow, and TP cannot be assumed.

The multiple regression equation was applied to the monthly TP concentrations collected by Ecology, and the mean daily streamflow reported by USGS at the mouth of Hangman Creek.

Changes in the TP laboratory analytical procedure over the period of record required that data first be adjusted. A statewide evaluation of TP data collected by Ecology was conducted by the Environmental Assessment Program at Ecology. The evaluation reported significant biases in the TP data based on analytical method (EAP, 2007).

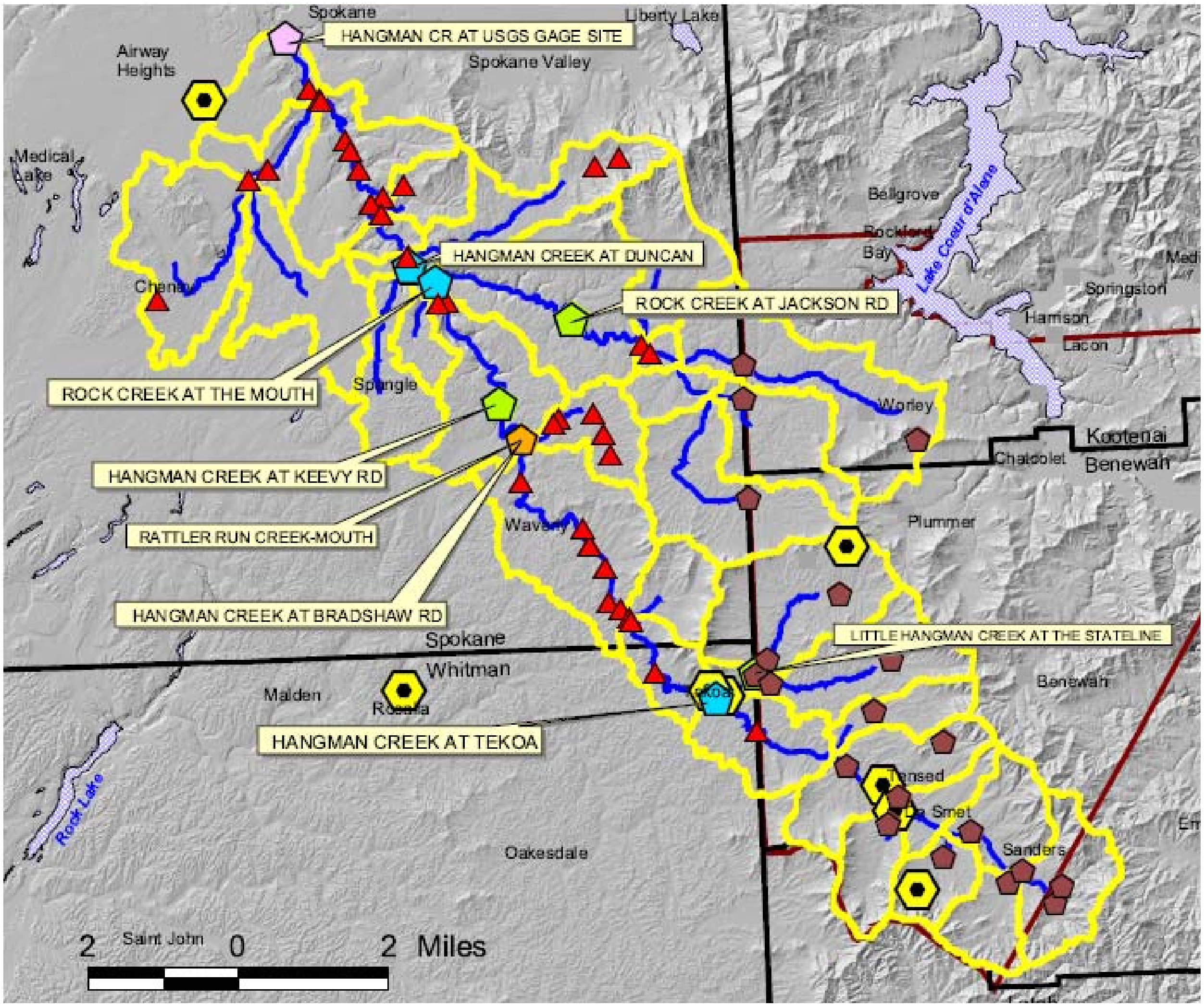


Figure P7. Delineated catchments and stream layout for the Hangman Creek Watershed Analysis Risk Management Framework (WARMF) model (Cadmus Group and CDM, 2007).

The original and adjusted datasets are shown in Appendix X. Three periods of data using different methods were present in the Hangman Creek TP record used in this study:

1. before January 1999
2. January 1999 – September 2003, and
3. October 2003 to September 2006).

The two earlier periods used colorimetric techniques but with different digestion processes (EPA 365.1 and Standard Methods 4500PI), and the last period analyzed samples using an inductively coupled plasma and mass spectrophotometer method (EPA 200.8M).

Adjusting the data significantly improved the goodness-of-fit statistics for the multiple regression equation (Figure P8). The Nash-Sutcliffe coefficient was used to evaluate the model fit to observed data. The model fit the observed total phosphorus load very well with a Nash-Sutcliffe coefficient of 0.95, where 1.0 is ideal.

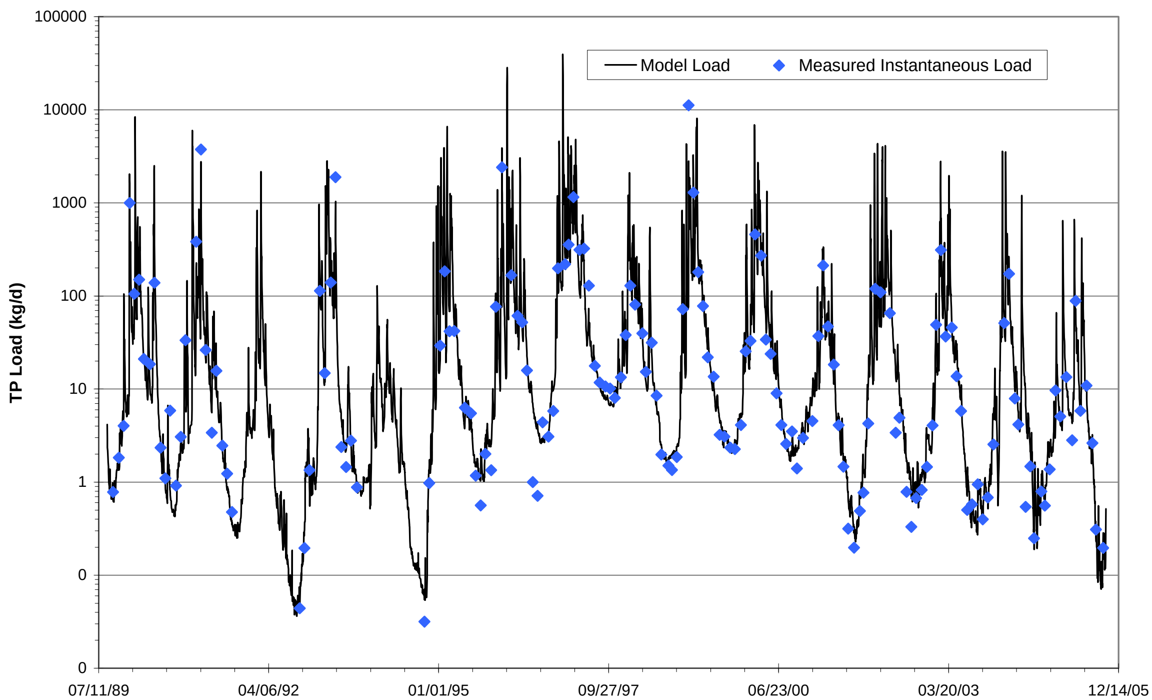


Figure P8. Observed total phosphorus loads (adjusted data – see text) at the mouth of Hangman Creek (56A070) compared to the Cohn model multiple regression output.

Although modeled by different procedures, the current Hangman Creek TP loads based on the multiple regression model and the loads used in the CE-QUAL-W2 model for the Spokane River Dissolved Oxygen TMDL (Ecology, 2007) closely match. A comparison of model outputs for monthly average TP loads in 2001 is shown in Table P1. The 2001 low-flow year was used to set the TP load capacity for the Spokane River and Lake Spokane. April to May and June to October seasonal average daily load estimates were only different by 1 lb TP/day.

Table P1. A comparison of 2001 monthly average total phosphorus load estimates (in pounds/day) based on the revised CE-QUAL-W2 models used for the Spokane River Dissolved Oxygen TMDL (Ecology, 2007) and the multiple regression model used for the Hangman Creek total phosphorus TMDL in this report.

Model	April	May	June	July	August	September	October
Revised CE-QUAL-W2	92	73.2	11.5	5.1	1.6	1.1	2.1
Multiple Regression	98	71	8.3	4.2	1.4	0.7	1.6

The WARMF landscape model also was calibrated to the long-term USGS streamflow data at the mouth of Hangman Creek (USGS 12424003), and to several shorter-term the SCCD gage sites in the watershed from October 1998 through September 2005:

- Hangman Creek at Duncan
- Rock Creek
- Rattler Run
- Hangman Creek at Bradshaw Road
- Hangman Creek at Tekoa

Climate is an important driver for the model. Accurate rainfall and temperature data are necessary to generate the streamflow quantities in the catchments. Unfortunately, the two meteorological stations in Washington with nearly complete data sets are outside the eastern edge of the Hangman Creek watershed at the Spokane Airport and Rosalia. Incomplete records are available for stations at Plummer and near Tensed, Idaho. A great number of missing records for these latter two stations had to be estimated to run the model. Future modeling work would be enhanced with more reliable data specifically targeted within the watershed.

Phosphorus and suspended sediment data were used from the Ecology site at the mouth (56A070) collected from October 1998 to September 2005. SCCD, Coeur d'Alene Tribe, and Ecology water quality data within the 1998 to 2005 timeframe were also used from various sites throughout the watershed. Point source data from NPDES permit reports were augmented by samples collected during the SCCD TMDL surveys in 2004 (SCCD, 2005a). The intermittent and small water quality data sets at most of these instream sites and point sources meant that calibration was not highly accurate for many areas of the watershed.

The initial hydrological calibration of the model by Cadmus Group and CDM (2007) was good considering the available data: higher flows in the watershed were simulated quite well, but the model over-estimated the low flow period. The Nash-Sutcliffe coefficient for flows at the mouth of Hangman Creek was 0.68 (Cadmus Group and CDM, 2007). After the calibrated model was delivered by the consultants, additional data were collected to refine streamflow and phosphorus simulations.

Refinements to the model were made to better simulate streamflow conditions:

- More SCCD rating curves were used in the model for tributaries and mainstem locations.
- Catchment widths in the Rock Creek sub-watershed were adjusted to prevent unrealistic runoff and erosion.
- Some cropping factors for various land uses were found to be outside the range of recommended values in the initial calibration, so they were adjusted accordingly.
- The discharge from the Rockford wastewater treatment plant (WWTP) was changed from continuous to seasonal (February through April).
- The Cheney WWTP was modified from continuous discharge directly to Minnie Creek, to a large onsite system to simulate the current wetland treatment system without a surface discharge.

- Ten percent of the assigned conventional agricultural land use was shifted into direct seed/conservation agriculture with a different set of system coefficient parameters.

The final version of the WARMF model by Ecology brought the water balance of the low-flow period into better calibration (Figure P9a). The Nash-Sutcliffe coefficient for 56A070 flows at the mouth of Hangman was 0.75, and 0.58 for all USGS flows. Cumulative runoff volume plots demonstrated that the model was capable of simulating total annual outflow over several years (Figure P9b). The model still over-predicted run-off in the low-flow period, especially during drier years e.g., 2001, 2003, and 2005. It slightly under-predicted the high flow period and missed the peak flow timing. Frequent spiking in the simulated flows compared to the observed data needs to be remedied in future model refinements.

The WARMF total phosphorus (TP) calibration proved to be even more difficult. The associations of TP with soil and sediment as affected by streamflow were helpful. However, few local data were available for estimating background phosphorus concentrations in soils/air/vegetation/water, and for determining transport and biological uptake rates. The total phosphorus loads from on-site systems, municipal wastewater treatment plants, and nonpoint sources were entered into the model based on few specific data sets.

In addition to the changes stated above for the hydrologic parameters, other phosphorus-related refinements were made:

- Initial soluble phosphorus soil concentrations were reduced from a 0.06 mg/L for all catchments to a range of 0.005 mg/L to 0.04 mg/L depending on location.
- Bed sediment and streambank TP concentrations were entered based on observed (unpublished data, personal communication Rick Noll, SCCD, 2007) catchment average concentrations (250 – 800 mg/kg).
- Septic tank and WWTP effluent TP concentrations and loading rates were adjusted to better conform to literature and observed data.
- More accurate enumeration of on-site septic systems provided by Spokane County and Coeur d'Alene Tribe were entered.

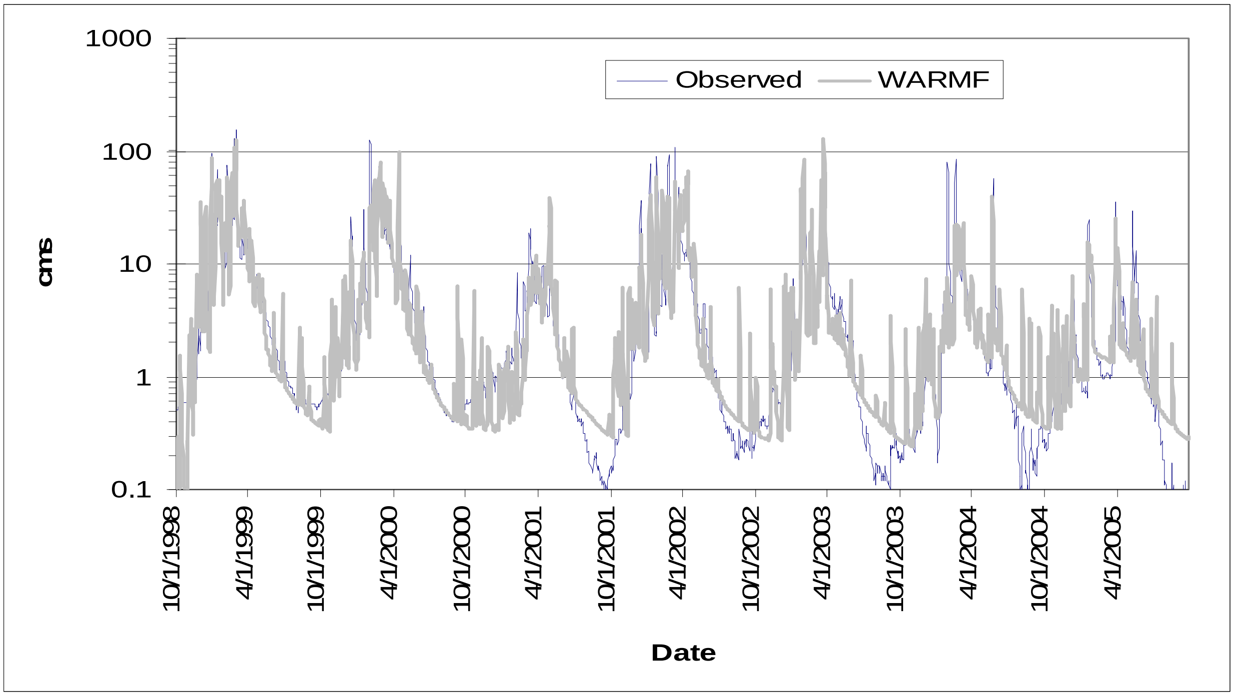
The calibrated WARMF phosphorus concentration and load simulations at the mouth of Hangman Creek are compared to the adjusted TP data in Figure P10a and P10b. As with the streamflow output, the simulated TP concentrations and loads during the low-flow period are over-predicted and some high values are under-predicted. For example, the WARMF and the multiple regression models had mixed comparability of monthly and seasonal average TP loads for the years 2000, 2001, and 2002 (Table P2). The monthly and seasonal statistics match a bit better during the wetter 2000 and 2002 than the drier 2001.

Some of the differences are due to the hydrological over-prediction of low-flows in the WARMF model. But the WARMF model seasonal biological uptake of TP and its release during aquatic plant and reed canary grass decay were not simulated. These functions may determine some of the timing of high and low phosphorus concentrations and loads. Also, since some factors in the model are set once, any changes in cropping patterns and land uses from 1998 to 2005 are not simulated. The relatively low Nash-Sutcliffe coefficient of 0.11 indicates the model is a slightly better predictor of TP load than the observed mean load.

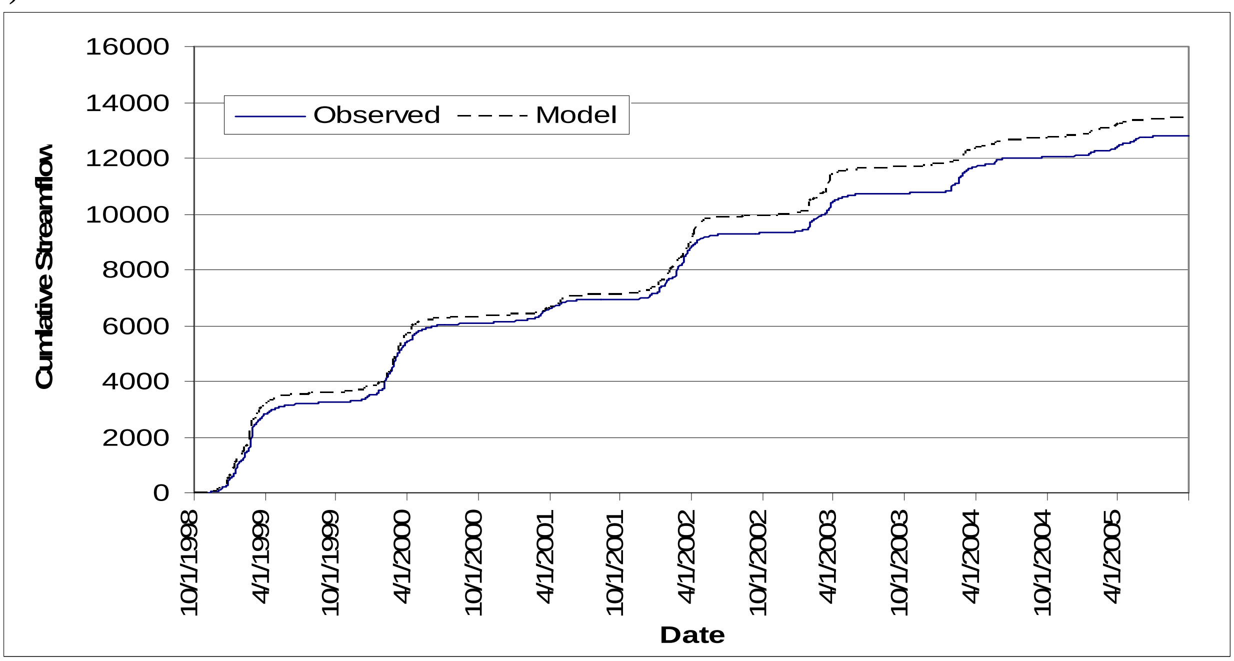
Table P2. A comparison of monthly and seasonal total phosphorus loads (lbs/day) for 2001 to 2003 at the mouth of Hangman Creek generated by the multiple regression equation model and Watershed Analysis Risk Management Framework (WARMF) model.

	2000		**2001**		**2002**	
Month	Multiple Regression	WARMF Model	Multiple Regression	WARMF Model	Multiple Regression	WARMF Model
April	364	384	98	144	260	370
May	81	39	71	138	42	43
June	35	13	8.3	8.4	14	9.3
July	12	7.7	4.2	5.7	4.2	5.6
August	5.0	5.8	1.4	4.6	2.0	4.5
September	4.9	7.3	0.7	4.3	2.1	4.3
October	5.6	6.8	1.6	7.1	2.6	4.3
Seasonal						
April - May	220	209	84	141	149	204
June - October	12.3	8.0	3.2	6.0	5.0	5.6

There was mixed success with calibrating the hydrology and phosphorus patterns within the watershed above the mouth. Few calibration data were available, especially for phosphorus. Future monitoring efforts in the watershed should focus on remedies for this situation. Model output for streamflow and phosphorus at key points in the watershed are shown in Appendix XXX.

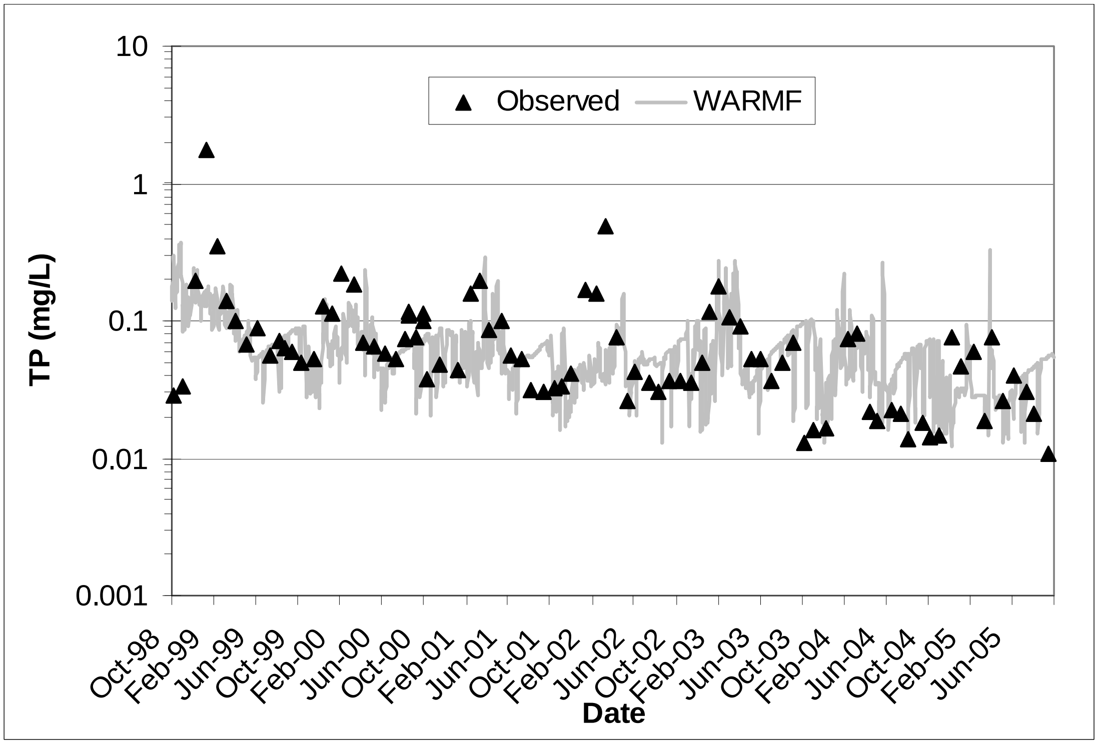


a)

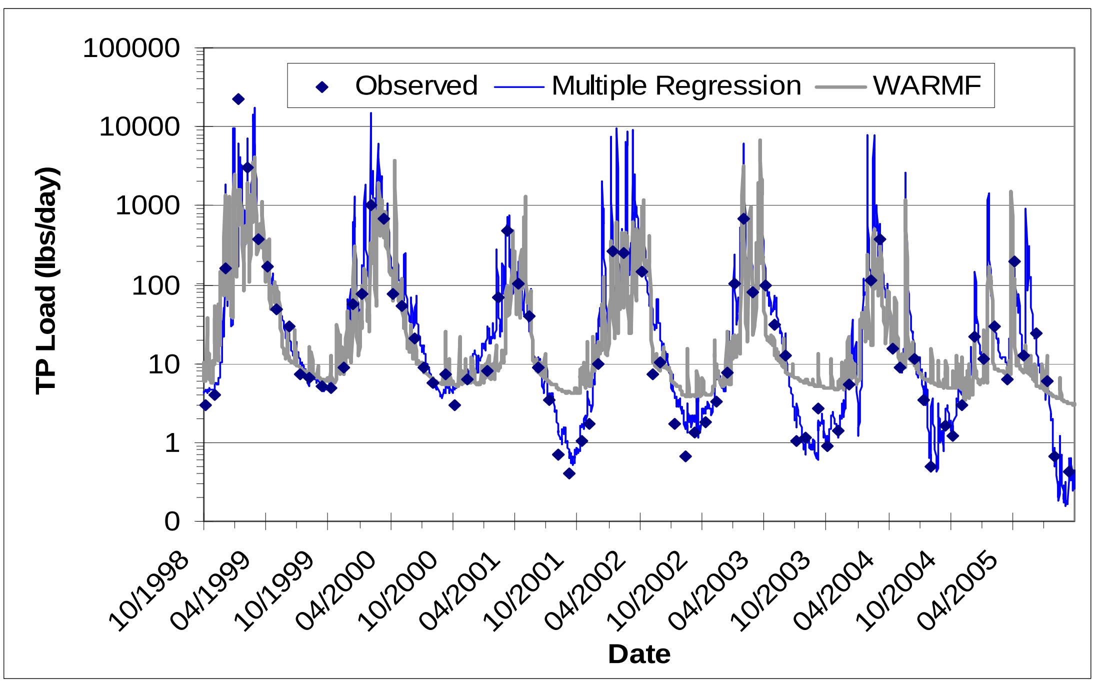


b)

Figure P9. Watershed Analysis Risk Management Framework (WARMF) model of Hangman Creek (Cadmus and CDM, 2007) hydrological calibration output compared to observed streamflow data: a) daily streamflow simulation b) cumulative flow volume for 1998-2005.



a)



b)

Figure P10. a) Watershed Analysis Risk Management Framework (WARMF) model output of total phosphorus (TP) concentrations compared to observed (adjusted) total phosphorus (TP) data, and b) a comparison of TP loads from WARMF and the multiple-regression models output, and observed (adjusted) instantaneous loads for the mouth of Hangman Creek.

Loading capacity

Current Loads Compared to Spokane River TMDL allocations

Hangman Creek is required to meet a set of phosphorus load allocations to the Spokane River for the months of April through October (Table S2). Therefore, in this TMDL the total phosphorus (TP) loading capacity at the mouth of Hangman Creek should be based on the loading capacity of the Lake Spokane and the Spokane River. Not enough is known about eutrophication potential within the watershed to determine the TP load capacities at affected sites.

However, some assumptions made by Ecology in the Spokane River and Lake Spokane TMDL may not be the same as assumptions made for the Hangman Creek total phosphorus TMDL. The primary area of difference concerns natural conditions and phosphorus generation in the Hangman Creek watershed that may be different from other areas of the Spokane River Basin. These differences were not realized when the Spokane River TMDL was developed. We will discuss how to interpret these differences as we evaluate watershed loading capacity.

The multiple regression model was used to estimate daily TP loads from monthly sampling and daily average flow data at the mouth of Hangman Creek. The monthly and seasonal averages of the estimated daily loads for various years were compared to the Spokane River TMDL load allocations to identify months or years where TP loads met and did not meet the allocations under current conditions. The results of these comparisons provide the first analytical tool for evaluating the TP loading capacity in Hangman Creek.

In Table P3 and Figure P11 the multiple regression model output are compared to the average monthly and seasonal Spokane TMDL load allocations. According to the model estimates, none of the allocations was met in Hangman Creek any month of the years 1996 – 2000, 2002 and most of 2004. The allocations were met in some months as shown by the 13 bold values in Table P3, mainly during the low-flow season of 2001, 2003 and 2005. The June-October average seasonal allocation was met in 2001 and 2003.

The April and May seasonal average of 50.6 lbs/day TP was not met in any year though April and May monthly allocations were met each once. Hangman Creek's future compliance with the Spokane River TMDL will most likely be judged on a seasonal average basis to conserve monitoring resources and take daily variability within the season into account. Compliance will also be judged relative to how close the year resembles a low-flow condition, i.e. seasonal TP loads in years with hydrology similar to 2001 will be expected to meet the allocation targets.

The multiple regression output for average monthly TP concentrations for 1996 through 2005 compared to Spokane River TMDL allocation concentrations is shown in Figure P12. Since 2001, average TP concentrations usually have been lower than allocation concentrations in August through October. Most have been higher than allocation concentrations in the months of April through July.

Day to day TP concentration and streamflow variability will be a problem for compliance assessment. The model's daily TP load output suggests that in several years the load allocation was met in more than half of the days in month even though the monthly average was not in compliance, most commonly in April, May, and July. For example, 21 days in May 2004 had a daily TP load below 40.6 lbs/day, but the monthly average was 167 lbs/day. Only rarely did the daily average TP concentrations in more than half the days of a month result in the monthly average not being in compliance with the load allocation. Compliance with TMDL targets could be easily misjudged if seasonal sampling strategy isn't taken into consideration.

Table P3. Monthly total phosphorus loads in units of pounds per day (lbs/day) estimated from the multiple regression model based on data collected from the mouth of Hangman Creek from 1996 to 2005 (adjusted data). The Spokane River Dissolved Oxygen TMDL monthly load allocations for Hangman Creek are shown for comparison from Ecology (2007). Values bolded meet the Ecology 2007 load allocations.

Year	April	May	June	July	August	September	October	April-May	June – October
1996	661	168	31	13	7.1	6.4	13	410	14
1997	529	234	71	36	21	17	15	379	32
1998	75	145	39	11	4.5	3.9	4.6	111	13
1999	138	47	19	10	6.6	5.4	6.5	92	9.5
2000	364	81	35	11	4.8	4.9	5.6	220	12
2001	98	71	**8.3**	4.2	1.4	**0.7**	**1.6**	84	**3.2**
2002	260	42	14	4.2	2.0	2.1	3.0	149	5.0
2003	92	**37**	**8.0**	**1.7**	**0.9**	1.4	**1.6**	64	**2.7**
2004	**31**	167	22	5.1	1.5	1.8	3.0	100	6.5
2005	72	115	13	**3.7**	**0.4**	**0.4**	**1.4**	94	3.7
Load Allocation	60.6	40.6	8.3	3.8	1.3	1.0	2.1	50.6	3.3

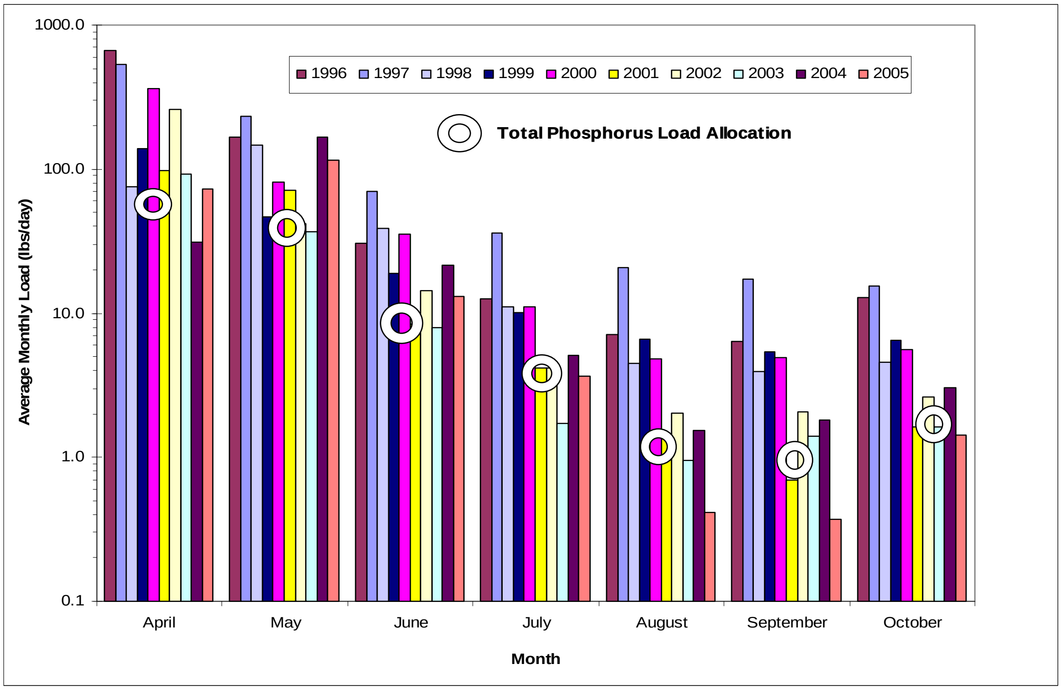


Figure P11. Average monthly total phosphorus (TP) loads based on the multiple regression model for the months of April – October from 1996 – 2005 compared to the recommended monthly TP loads from the Spokane River TMDL from Ecology, 2007.

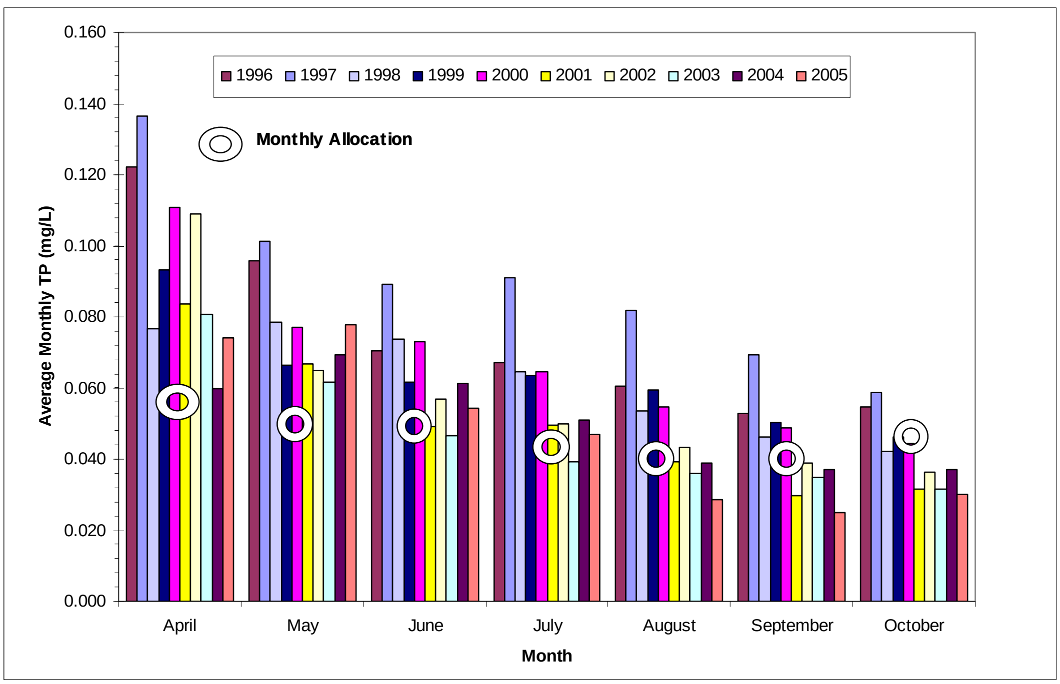


Figure P12. Average monthly total phosphorus (TP) concentrations at the mouth of Hangman Creek based on the multiple regression model for the months of April through October from 1996 – 2005 compared to the recommended monthly TP concentrations from the Spokane River TMDL based on 2001 low-flow conditions.

As described earlier, the Spokane River TMDL study to restore dissolved oxygen (DO) concentrations in Long/Spokane Lake recommended seasonal phosphorus limits for Hangman Creek (Cusimano, 2004). Load allocations were incrementally added to tributary sources until a 0.2 mg/L DO loss in the lake compared to natural conditions was observed in the CE-QUAL-W2 model output (Ecology, 2007). These monthly load allocations were compared to phosphorus, nitrogen, and carbonaceous biochemical oxygen demand (CBOD) loading during 2001 critical conditions (a low-flow year) to determine necessary reductions to meet the DO target.

So, the monthly and seasonal TP load allocations include an estimate of natural conditions plus a load allocation for nonpoint sources (NPS). (In the Spokane River TMDL, 'nonpoint' presumably includes small point sources and stormwater sources under permit in the Hangman watershed.) The assumed monthly natural condition concentrations for Hangman Creek of 0.018 to 0.02 mg/L are higher than the 0.008 mg/L USEPA reference recommendations for the Northern Rockies ecoregion, but lower than the 0.03 mg/L for the Columbia Plateau ecoregion (Table S2 – Page 24). The Spokane River TMDL natural background assumptions were made before work in the Hangman Creek TMDL began.

The resulting seasonal average TP load allocations (LA) for Hangman Creek contain natural condition loads of 19 lbs/day for April and May, and 1.3 lbs/day for June through October at 2001 streamflows. The NPS portions added to the natural loads are 31.6 lbs/day for April and May and 2.0 lbs/day for June to October. Theoretically, if the natural conditions load for Hangman Creek are higher or lower, the NPS TP loads could remain the same because the goal of the Spokane River TMDL is not to attain one DO concentration in the lake, but to limit the DO decrease over natural conditions to 0.2 mg/L.

In summary, the multiple regression model suggests Hangman Creek often has met Ecology's (2007) Spokane River TMDL TP load allocations and target concentrations in the low-flow months of August through October in drier years since 2001. However, the monthly load allocations for April and May have rarely been met, and the April-May seasonal allocation never has been met, even in drier years. These estimates are based on data from current conditions without documented measures to specifically reduce TP in the Hangman watershed.

These multiple regression model results for 2001-2005 may be somewhat different from the CEQUAL-W2 model results used for the Spokane River DO TMDL. The small output differences in the 2001 monthly TP loads in Table P1 may become more pronounced in other years, and produce different interpretations of TMDL compliance. In addition, revised natural condition estimates for Hangman Creek in the future could make a significant difference in interpreting TMDL compliance. Since the TMDL allocations in the Spokane basin are built from the effect of natural conditions loads on Lake Spokane (Long Lake) DO, the allocation to Hangman Creek may be greater in April through June and smaller in July through October.

So, it is unlikely all Spokane River TMDL load allocations will be met in the future unless TP controls are implemented in the Hangman Creek watershed. Based on this information, TP load reductions will be necessary to meet the Spokane River allocations. But, the Spokane TP load allocations to Hangman Creek may need some adjustment as well, based on better natural conditions data.

Best potential loads compared to Spokane River TMDL allocations

Considering the disparity between the Hangman TP load allocation and the current loading conditions, the community questioned whether the TP load allocations could be met in April through July under any set of implementation activities. The Hangman Creek Advisory Committee questioned if the TP load capacity should be predicted from a pristine or natural state scenario. The following points were made:

- the channel and land use had changed greatly over the past centuries of human habitation
- no reference sub-watersheds were available for each of the diverse Ecoregions represented in the watershed

Therefore, the best potential or future reference condition for the watershed was based on a question put to the Hangman Creek Advisory Committee:

"What is the best possible set of actions that could be implemented in the Hangman Creek watershed to achieve phosphorus reductions?"

The recommendations by the Advisory Committee covered a wide range of progressive actions:

- Convert 60% of the agriculture in the watershed to direct seed or conservation practices.
- Have 10 foot riparian buffers established all along the mainstem channels and tributaries.*
- Reduce the streambank erosion in the upper watershed (above Fairfield) by 50% and erosion in the lower watershed with Lake Missoula flood sediments by 10%.
- Increase forest cover in catchments above Rockford and Tensed by 50%.
- Limit residential growth to levels below 10% in lower watershed (catchments 3, 4, 7, 9 and 10).
- Eliminate point source discharges to surface water.
- Repair failing residential on-site septic systems.

*Although the Natural Resource Conservation Service (NRCS) requires 35 feet buffers under their funding programs for establishing new buffers, the advisory committee felt 10 foot buffers throughout the watershed was a more accurate estimate of what could be achieved. Some stream reaches may have buffers greater than 35 feet, while it may be difficult to establish any buffer in other areas.

The calibrated WARMF model was used to estimate the effect of this set of best management practices (BMPs) to reduce phosphorus in Hangman Creek (Figure P13). Although the WARMF model calibration of observed TP data was not as closely matched as the multiple regression model, the results provide important insight into the response of TP sources in the watershed to actions. *The best potential scenario of BMPs is considered an estimate of the reference TP loading conditions to the Spokane River and represents the loading capacity of the watershed.*

An additional calculation was made to translate the best potential scenario estimates into TP loads more comparable with the Spokane River TMDL load allocations. The percentage TP reduction estimated by the difference between WARMF Current Conditions and Best Potential (Reference) simulations was applied on a monthly basis to the multiple regression model monthly TP load estimates. The reduced TP load estimates after actions are implemented are compared to the Spokane River TP load allocations (Table P4).

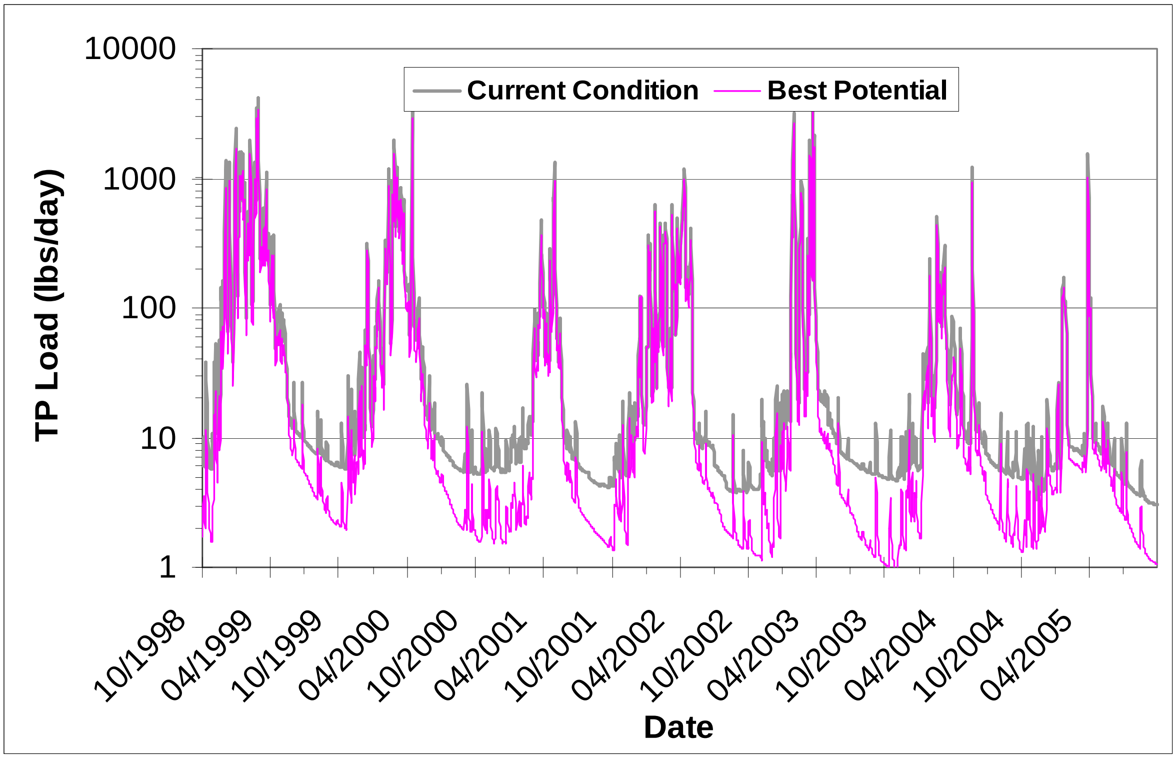


Figure P13. Current and best potential (Reference – see text) total phosphorus (Total P) loads in pounds/day at the mouth of Hangman Creek based on the WARMF model simulations.

Table P4. Monthly total phosphorus loads estimated by applying the percentage TP reductions from the WARMF Reference simulation to the multiple regression model output for the mouth of Hangman Creek from 1998 to 2005 in Table P3. Phosphorus loads are in units of pounds per day (lbs/day). The Spokane River Dissolved Oxygen TMDL monthly load allocations for Hangman Creek are shown for comparison Ecology (2007). Values bolded meet the Ecology 2007 load allocations.

Year	April	May	June	July	August	September	October	April - May	June – October
1998	-	-	-	-	-	-	**1.5**	-	-
1999	99	**32**	11	5.0	3.0	1.9	2.6	65	4.5
2000	284	55	20	5.7	1.8	2.0	**2.0**	169	5.5
2001	78	58	**4.5**	**1.8**	**0.6**	**0.2**	**0.7**	68	**1.4**
2002	210	**34**	**6.6**	**1.9**	**1.0**	**0.8**	**0.8**	120	**2.1**
2003	**54**	**22**	**3.6**	**0.6**	**0.2**	**0.4**	**0.4**	**37**	**0.8**
2004	**20**	137	13	**2.1**	**0.6**	**0.6**	**1.0**	78	**2.8**
2005	63	83	**7.6**	**1.9**	**0.2**	**0.1**	**-**	79	**-**
Load Allocation	60.6	40.6	8.3	3.8	1.3	1.0	2.1	50.6	3.3

Of particular interest with these estimates are the results for 2001, the Spokane River TMDL critical condition, and the low-flow years of 2003 and 2005. Under best potential conditions, April and May TP loads in 2001 would have been reduced by 20%. The model estimates suggest the loading capacity in 2001 was higher than the recommended April-May seasonal allocation of 50.6 lbs/day. The loading capacity for the June through October season has an estimated 55% TP reduction over current conditions and appears to comply with the recommended load allocation of 3.3 lbs/day.

Since 2001, streamflows in April were lower in 2003 to 2005, and May streamflows were as low or lower in 2002 and 2003 (Table HC1). The seasonal average April and May streamflows in 2003 to 2005 (150 cfs to 185 cfs) were similar to the 180 cfs in 2001. The model suggests that the loading capacity changes during statistically low-flow years. Load capacities were lower than the Spokane River monthly load allocations recommendations in April 2003 and 2004 and May 2002 and 2003 (Table P4). However, despite an estimated average seasonal TP reduction over current conditions of 24%, the April-May seasonal TP load capacity met the recommended seasonal load allocation only in 2003.

Almost all of the estimated monthly and seasonal June to October TP load capacities since 2001 appear to be within the load allocations recommended for the Spokane River TMDL. Although the WARMF model tends to overestimate the TP load during low-flow conditions, the results of the analysis seem reasonable. The multiple regression model suggests the Spokane River TMDL TP allocations were met, or nearly so, under current conditions in those months of 2001 (Table P3).

Spokane River and Lake Spokane dissolved oxygen responses to Hangman Creek TP loads under higher streamflow conditions have not been evaluated. The Spokane River TMDL was based on low-flow critical conditions to control point source loads. Tributaries cannot be put under as many controls as point sources. So, evaluating the effect of Hangman Creek and Little Spokane River TP loads on the Spokane River and Lake Spokane under average or high flow conditions may be necessary to ensure water quality in the entire system and develop Hangman Creek allocations for those conditions.

In summary, it appears that the TP loading capacity for Hangman Creek in the April – May season may be higher than the load allocation recommended by the Spokane River DO TMDL report (Ecology, 2007), i.e. the Spokane River TMDL allocations are too restrictive for April-May. The loading capacity from June to October appears to be within the seasonal load allocations in Table P4. Some of the primary TP sources indicated in the WARMF model are instream and bank sediments that are difficult to control, and may have a natural component. A higher natural TP concentration in the Hangman Creek watershed than initially assumed in the Spokane River model may be an area for future evaluation.

Future studies of dissolved oxygen (DO) and pH violations in the Hangman Creek watershed may require a more comprehensive set of TP loading capacities for select areas within the watershed if phosphorus is the limiting nutrient causing these violations. The cumulative TP loading capacity based on preventing these violations within different reaches of Hangman Creek may be far different from the one estimated here, and may have a different seasonal focus. Fortunately, phosphorus reductions and riparian shading recommended by this TMDL will bring water quality conditions closer to alleviating some local DO and pH problems.

Load and wasteload allocations

The WARMF model was used to evaluate point and nonpoint sources in the entire Hangman Creek watershed from October 1998 through September 2005. This was done in cooperation with the Coeur d'Alene Tribe and the State of Idaho at the request of Region 10 USEPA. A cooperative strategy between jurisdictions yields a more comprehensive approach to controlling TP sources in the watershed. However, the Washington State cannot dictate to the Coeur d'Alene Tribe and Idaho what measures they need to take in Hangman Creek.

The Idaho Department of Environmental Quality (IDEQ) has completed a TMDL for the upper 10,000 acres of the watershed in 2007. The TMDL did not include nutrient allocations because nutrients did not violate Idaho's water quality standards. The TMDL acknowledges that IDEQ may need to reevaluate nutrients to protect downstream beneficial uses if Washington's TMDL indicates reductions are necessary at the Idaho/Washington border. (IDEQ, 2007)

Whole Watershed Source Evaluation

The effect on average daily TP loads generated from land uses in Hangman Creek before and after applying the Advisory Committee's suggested best potential actions can be seen in Table P5. The change in average daily TP load to the Spokane River from the mouth of Hangman Creek and the sources of TP loads is shown in Figure P14. The analysis is multi-year and multi-season because TP loads generated in various parts of the watershed may not affect loads to the Spokane River until months or years later.

The analysis is based on an annual daily average load from October 1998 through September 2005. Both high and low-flow years are included so that generation, transport, and delivery from all types of TP sources are represented. As mentioned in the load capacity section previously, the best potential scenario represents the load capacity of the watershed. Implementation of the BMPs in the scenario results in an overall estimated 18% reduction in TP generation in the entire watershed from both point and nonpoint sources (Table P5). And, a 20% TP load reduction (TMDL category) in daily average loading to the Spokane River is realized (Figure P14).

Table P5. Estimated average daily total phosphorus (TP) loads generated by point and nonpoint sources in the Hangman Creek watershed. Estimated loads are from WARMF model simulations based on October 1998 to September 2005 conditions. Simulations of existing (Current) and best potential (Reference) conditions are compared.

Source	Current TP Load kg/day	Best Potential (Reference) TP Load kg/day	Percent TP Load Reduction
All Forest	8.2	8.4	-2.0%
Cropland / Pasture	54	23	16%
Direct Seed	4.2	25	
Rangeland	9.7	8.0	18%
Stream Bank Erosion	5.1	4.3	15%
Residential	2.5	2.6	-4.0%
Point Source	4.6	0.0	100%
Other	0.8	0.8	0.6%
Septic	0.3	0.3	7.9%
Total	**89**	**73**	**18%**

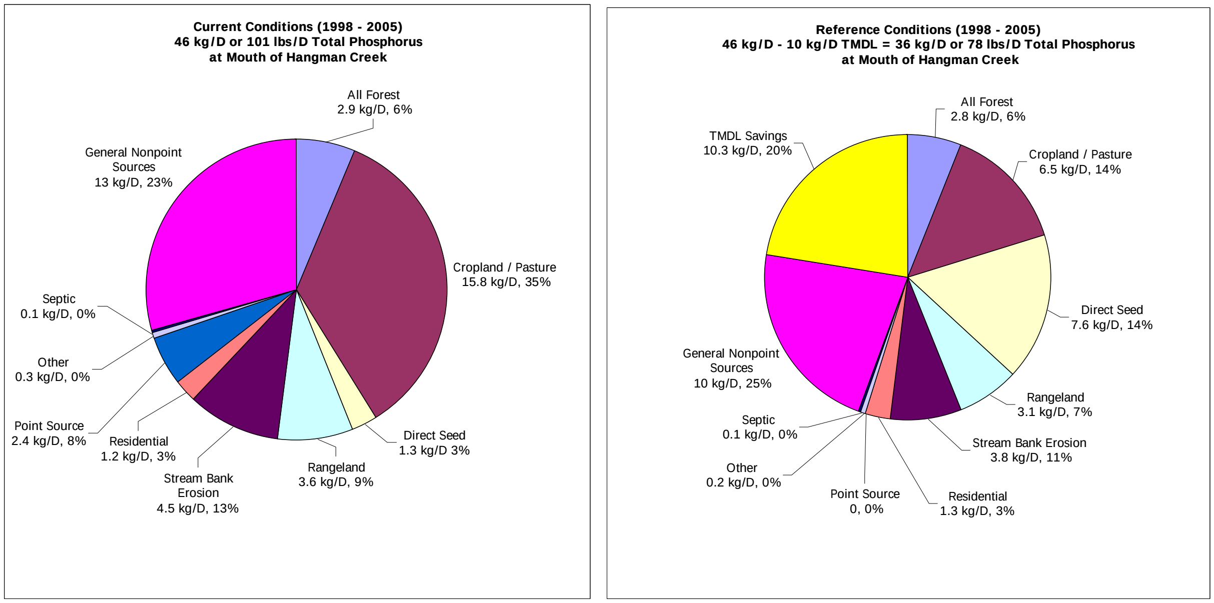


Figure P14. A comparison of estimated daily average total phosphorus loads at the mouth of Hangman Creek from various sources in the watershed under current and best potential (Reference) conditions based on WARMF model simulations of October 1998 to September 2005 conditions.

Background sources of TP were significant in both the current and best potential scenarios in Figure P14. ‘General Nonpoint Sources’ supplied one-fifth of each scenario’s annual average TP load. The General Nonpoint Sources category includes bed sediment TP loads and background water column and soil-water concentrations. The majority of this category’s contribution is TP load associated with bed sediment movement. A large portion of the category could be considered ‘natural’, but not enough is known about sediment, soil-water, and water column concentrations in undisturbed areas to partition the category.

Substantial increases in forest cover in the best potential scenario slightly increased the TP load (Table P5) from that category, but did not appreciably affect its average contribution to the TP load out of the watershed (Figure P14). Since no substantial changes in the wetland bases were made between scenarios, no TP effect was seen in that contribution of the ‘Other’ category.

Agricultural BMPs would reduce TP load (Cropland/Pasture + Direct Seed) generation by 15.8% (Table P5) and was responsible for 29%[1] of the TP reduction, or ‘TMDL savings’ (Figure P14). Rangeland TP loading was also reduced and accounted for 5% of the TP reduction, but partly because much of the rangeland in the upper watershed was converted to forest in the best potential scenario.

Targeted BMPs on other nonpoint sources reduced TP loads as well. Streambank TP loading from erosion would be reduced by 15% and accounted for 7% of the TMDL savings. Failing onsite septic system elimination would reduce overall TP share from all septic systems by 8%,

[1] Calculation: (15.8 + 1.3) – (6.5 + 7.6) = 3 and 3/10.3 = 29%

but it was an inconsequential reduction of the TMDL load to the Spokane River. The small increases in residential growth in the lower watershed did not substantially increase the TP load from Residential uses. Commercial land use was a small portion of the 'Other' category and was not targeted for BMPs so TP loading was unchanged.

Removing the point source TP loads resulted in 23% of the overall TMDL-associated reduction of TP exported from the watershed, i.e. 2.4 kg/day of the 10.3 kg/day. Point source effects are especially evident in the low-flow months, and are thought to be responsible for achieving the Spokane River TMDL June – October seasonal load allocations.

Coeur d'Alene and Idaho Total Phosphorus Loads

Approximately 35% of the Hangman Creek watershed lies in catchments in the Coeur d'Alene Indian Reservation and in Idaho. On average, up to 60% of the water is delivered from these catchments to Hangman Creek annually (Figure HC2). The headwater catchments of the mainstem Hangman Creek, Little Hangman Creek, and Rock Creek (Figure P7) are not within Washington's jurisdiction, but deliver TP loads that affect Hangman Creek and the Spokane River. The TP load from these catchments and the effect of cross-border implementation measures on reducing the load are shown in Figure P15.

Under the Current condition scenario, the cross-border catchments delivered an average daily cumulative TP load of 22 kg/day, compared to 46 kg/day TP delivered to the Spokane River from Hangman Creek (Figure P15) on an average annual basis over the 1998 – 2005 simulation period. Upper Rock Creek catchments accounted for about 25% of the cross-border load, especially from Cropland and Pasture lands. Little Hangman and upper mainstem catchments contributed 33% and 40%, respectively. The Tensed Wastewater Treatment Plant (WWTP) also contributed a significant TP load from the upper mainstem (Figure P15).

Cross-border TP loads vary from year to year. Also, the transport of the TP load in one month or one season from the upper watershed may not be transported downstream to the mouth in that same period. So, it would not be accurate to express a percentage of the load at the mouth as cross-border during a unique critical condition. The transport time depends on the streamflow energy that is available, channel characteristics, and aquatic community uptake rates. Therefore, annual TP loads coming across the border cannot be directly measured against TP loads delivered by Hangman Creek to the Spokane River except as long-term averages.

The model estimates that best potential condition actions reduce the cumulative cross-border TP loads by 18%. Application of BMPs to crop and pasture lands and removal of the Tensed WWTP comprised most of the load reduction. Most of the conversions from range to forest take place across the border. The TP load allocations for the upstream catchments will need to be negotiated with the Coeur d'Alene Tribe and Idaho through USEPA Region 10. For example, Idaho's 10,000 acres in the upper watershed has already been through the TMDL process and has been approved by USEPA (IDEQ, 2007). In that analysis, current nutrient conditions were considered under control.

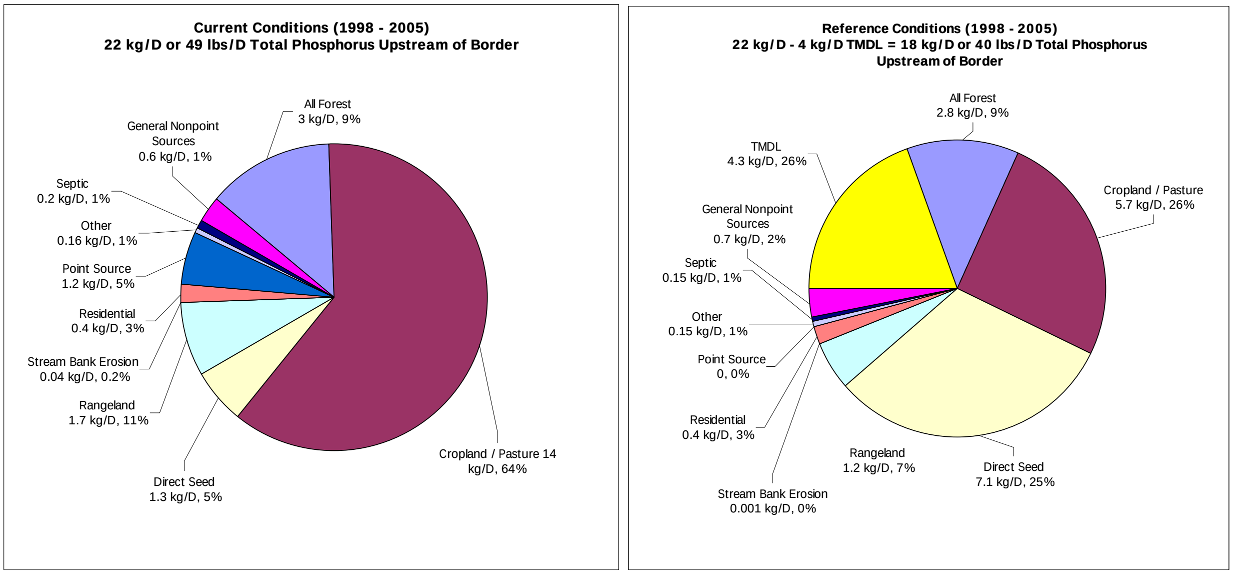


Figure P15. A comparison of estimated daily total phosphorus loads delivered from various sources in catchments of the Hangman Creek watershed located upstream of the Washington/Idaho border (Rock Creek, Little Hangman Creek and upper Hangman Creek). Loads delivered under current and best potential (Reference) conditions are shown for WARMF model simulations of October 1998 to September 2005.

Cross-border TP loads vary from year to year. Also, the transport of the TP load in one month or one season from the upper watershed may not be transported downstream to the mouth in that same period. So, it would not be accurate to express a percentage of the load at the mouth as cross-border during a unique critical condition. The transport time depends on the streamflow energy that is available, channel characteristics, and aquatic community uptake rates. Therefore, annual TP loads coming across the border cannot be directly measured against TP loads delivered by Hangman Creek to the Spokane River except as long-term averages.

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Sub-watershed Source Evaluation

Hangman Creek was divided into six sub-watersheds in the WARMF model to examine various regional sources of TP and to help direct future implementation actions (Figure P16):

- Hangman Creek mainstem upstream of the Washington/Idaho border

- Hangman Creek upstream of Bradshaw including Little Hangman Creek Watershed
- Hangman Creek upstream of Duncan including Rattler Run
- Rock Creek sub-watershed
- Marshall Creek sub-watershed
- Lower Hangman Creek including Spangle and California Creek catchments

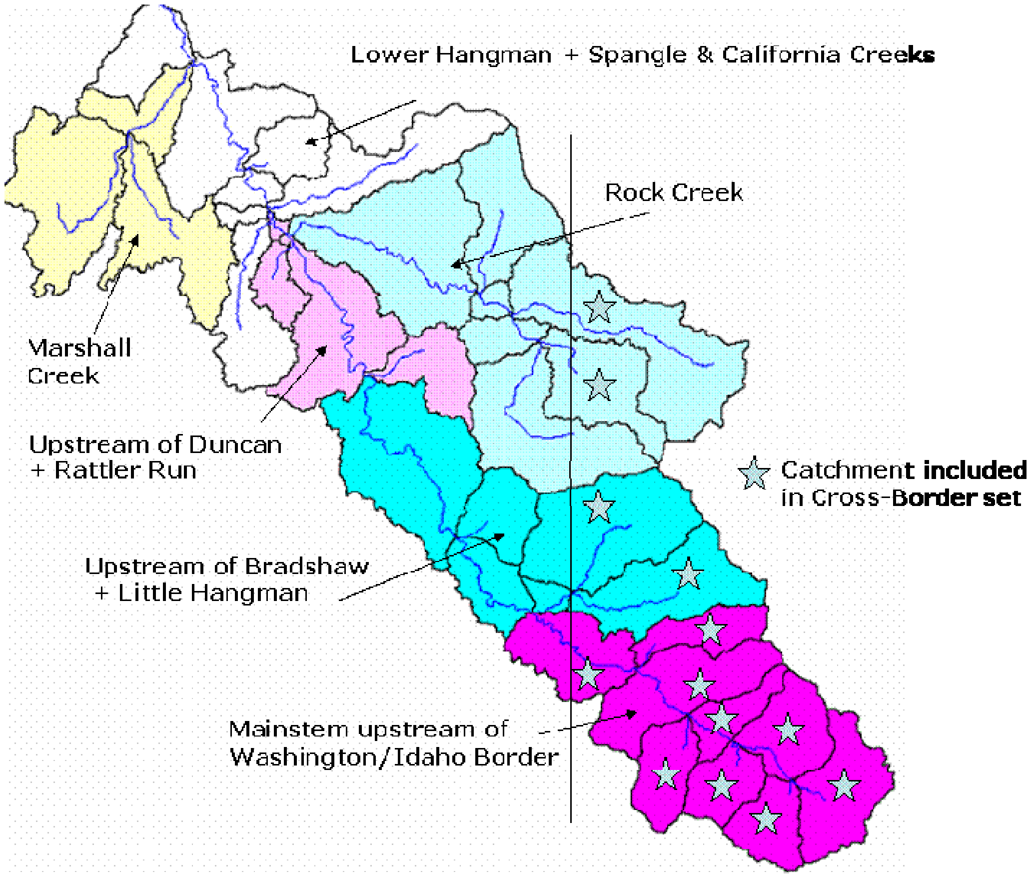


Figure P16. Hangman Creek sub-watersheds delineated in the WARMF model and catchments included in calculating cross-border loading.

The WARMF model simulations provide an estimate of TP generation in, and transport through the sub-watersheds. Table P6 provides a summary of where in the watershed TP loads are generated over the long-term. This summary is based on the average daily load generated by sources over the 1998 – 2005 simulation period. The pie charts in Figure P17 compare current and best potential scenario TP loads leaving each of the five upper sub-watersheds on a long-term average daily basis. Sub-watersheds along the main stem of Hangman Creek include cumulative loads from tributaries and upstream reaches. The Lower Hangman Creek sub-watershed results were shown in Figure P14.

The influence of agricultural sources on TP loads is demonstrated in the sub-watershed assessments (Figures P14 and P17). Approximately 55% of the land base in the Hangman Creek watershed is in conventional or conservation agriculture/pasture use. About the same percentage of the total TP load in the current scenarios of five upper sub-watersheds is delivered by agriculture/pasture sources (Figure P17). The estimated TP load from agriculture increases from 6 kg/day in the Upper Hangman sub-watershed to 17 kg/day in Hangman above Duncan and the Lower Hangman sub-watershed at the mouth (Figure P17).

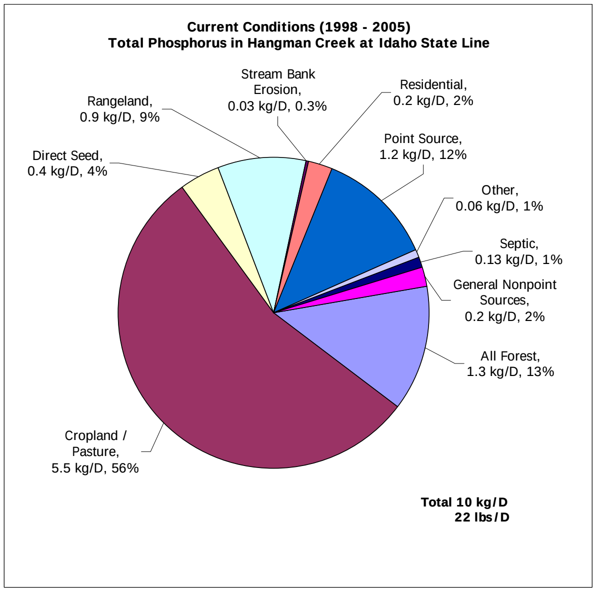
A comparison of Table P6 statistics to Figure P17 results also suggests that, on average, much of the TP load generated in the watershed is stored in key sub-watersheds. The Little Hangman & Hangman from Tekoa to Bradshaw sub-basin generates a larger TP load than it discharges downstream. Likewise, the Rock Creek and Lower Hangman Creek sub-watersheds store TP loads. Some of the long-term TP stored in the Lower Hangman may be part of the General Nonpoint Category, as was discussed in Figure P14.

The WARMF model results appear to show streambank erosion only as a major TP load contributor in the Lower Hangman sub-watershed (Figure P14). The model parameters may be underestimating the association of TP to streambank erosion in the upper sub-watershed, but local streambank erosion rates have not been measured. The banks consisting of Missoula Flood sediments are a known problem in the Lower Hangman reaches.

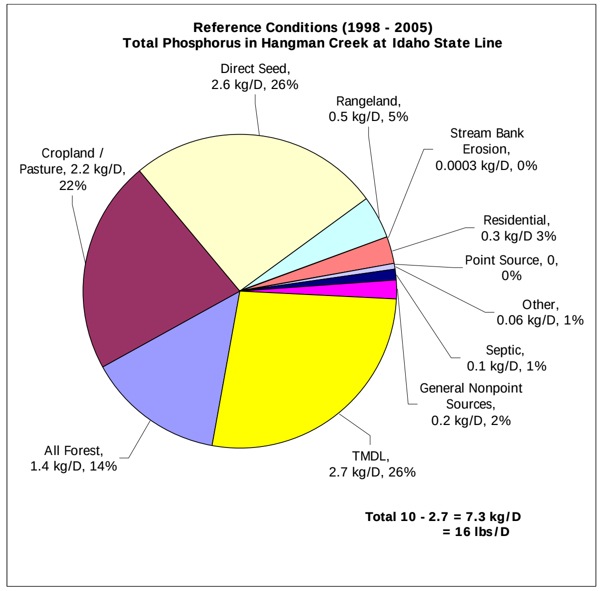
Table P6. Estimates of total phosphorus loads generated in each sub-watershed under current and best potential WARMF model simulations relative to the total load generated in the Hangman Creek watershed. The percentage of land area in each sub-watershed is also shown.

	Current	**Reference**	**Land Area**
Upper Hangman	25%	23%	20%
Little Hangman & Hangman from Tekoa to Bradshaw	37%	38%	19%
Hangman from Bradshaw to Duncan & Rattler Run	2%	1%	8%
Rock Creek	20%	20%	27%
Marshall Creek	3%	3%	11%
Lower Hangman	14%	15%	15%

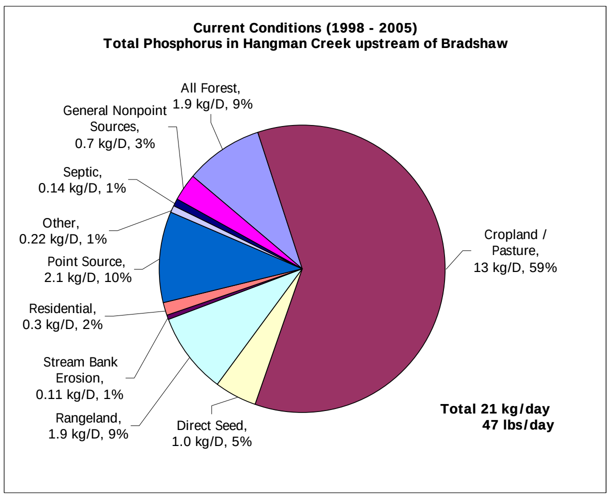
The best potential scenario results suggest improvements can be made in reducing cumulative TP loads from agriculture, streambank erosion, and point sources in most sub-watersheds by 14% to 26% ('TMDL' slices in Figure P17). Even General Nonpoint Sources may be reduced in the Lower Hangman sub-watershed if BMPs are implemented. As an exception, Marshall Creek watershed TP loads do not appear to respond very much to practices implemented for the best potential scenario (1% TMDL in Figure P17). Marshall Creek should continue to be a minor source of direct TP loading unless the Cheney WWTP wetlands begin to discharge to surface waters or the wetlands create a groundwater problem not yet evident in the data.



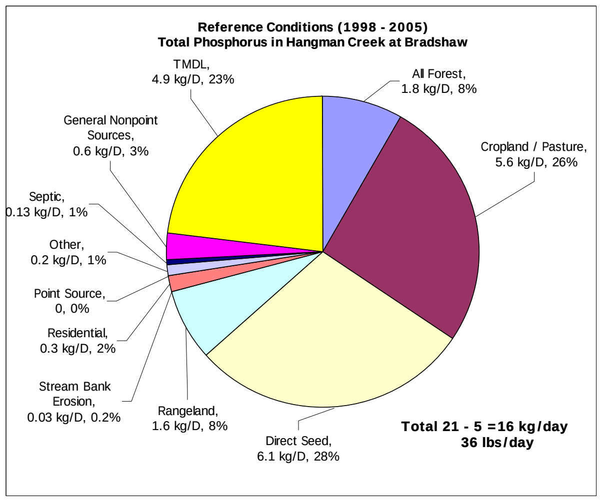
Current Conditions (1998 - 2005)
Total Phosphorus in Hangman Creek at Idaho State Line
Stream Bank Erosion, 0.03 kg/D, 0.3%
Residential, 0.2 kg/D, 2%
Rangeland, 0.9 kg/D, 9%
Point Source, 1.2 kg/D, 12%
Direct Seed, 0.4 kg/D, 4%
Other, 0.06 kg/D, 1%
Septic, 0.13 kg/D, 1%
General Nonpoint Sources, 0.2 kg/D, 2%
All Forest, 1.3 kg/D, 13%
Cropland / Pasture, 5.5 kg/D, 56%
Total 10 kg/D
22 lbs/D



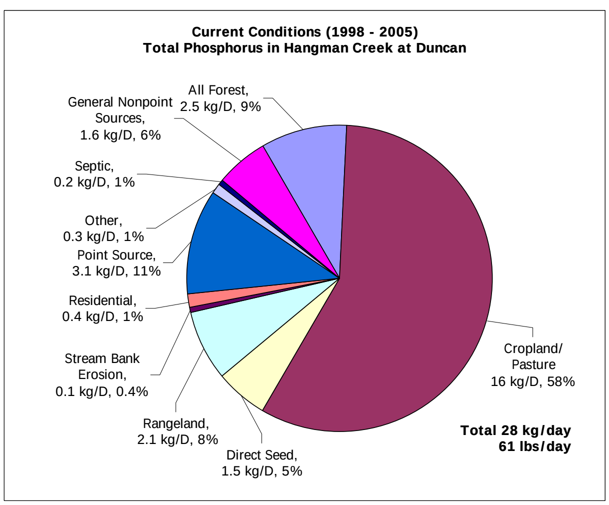
Reference Conditions (1998 - 2005)
Total Phosphorus in Hangman Creek at Idaho State Line
Direct Seed, 2.6 kg/D, 26%
Rangeland, 0.5 kg/D, 5%
Stream Bank Erosion, 0.0003 kg/D, 0%
Cropland / Pasture, 2.2 kg/D, 22%
Residential, 0.3 kg/D 3%
Point Source, 0, 0%
Other, 0.06 kg/D, 1%
Septic, 0.1 kg/D, 1%
General Nonpoint Sources, 0.2 kg/D, 2%
All Forest, 1.4 kg/D, 14%
TMDL, 2.7 kg/D, 26%
Total 10 - 2.7 = 7.3 kg/D
= 16 lbs/D



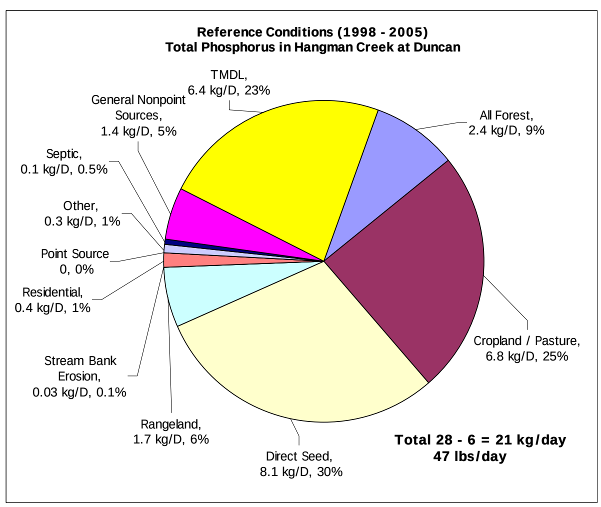
Current Conditions (1998 - 2005)
Total Phosphorus in Hangman Creek upstream of Bradshaw
All Forest, 1.9 kg/D, 9%
General Nonpoint Sources, 0.7 kg/D, 3%
Septic, 0.14 kg/D, 1%
Other, 0.22 kg/D, 1%
Cropland / Pasture, 13 kg/D, 59%
Point Source, 2.1 kg/D, 10%
Residential, 0.3 kg/D, 2%
Stream Bank Erosion, 0.11 kg/D, 1%
Rangeland, 1.9 kg/D, 9%
Direct Seed, 1.0 kg/D, 5%
Total 21 kg/day
47 lbs/day



Reference Conditions (1998 - 2005)
Total Phosphorus in Hangman Creek at Bradshaw
TMDL, 4.9 kg/D, 23%
All Forest, 1.8 kg/D, 8%
General Nonpoint Sources, 0.6 kg/D, 3%
Cropland / Pasture, 5.6 kg/D, 26%
Septic, 0.13 kg/D, 1%
Other, 0.2 kg/D, 1%
Point Source, 0, 0%
Residential, 0.3 kg/D, 2%
Stream Bank Erosion, 0.03 kg/D, 0.2%
Rangeland, 1.6 kg/D, 8%
Direct Seed, 6.1 kg/D, 28%
Total 21 - 5 =16 kg/day
36 lbs/day



Current Conditions (1998 - 2005)
Total Phosphorus in Hangman Creek at Duncan
All Forest, 2.5 kg/D, 9%
General Nonpoint Sources, 1.6 kg/D, 6%
Septic, 0.2 kg/D, 1%
Other, 0.3 kg/D, 1%
Point Source, 3.1 kg/D, 11%
Residential, 0.4 kg/D, 1%
Cropland/ Pasture 16 kg/D, 58%
Stream Bank Erosion, 0.1 kg/D, 0.4%
Rangeland, 2.1 kg/D, 8%
Direct Seed, 1.5 kg/D, 5%
Total 28 kg/day
61 lbs/day



Reference Conditions (1998 - 2005)
Total Phosphorus in Hangman Creek at Duncan
TMDL, 6.4 kg/D, 23%
General Nonpoint Sources, 1.4 kg/D, 5%
All Forest, 2.4 kg/D, 9%
Septic, 0.1 kg/D, 0.5%
Other, 0.3 kg/D, 1%
Point Source 0, 0%
Residential, 0.4 kg/D, 1%
Cropland / Pasture, 6.8 kg/D, 25%
Stream Bank Erosion, 0.03 kg/D, 0.1%
Rangeland, 1.7 kg/D, 6%
Direct Seed, 8.1 kg/D, 30%
Total 28 - 6 = 21 kg/day
47 lbs/day

Figure P17.

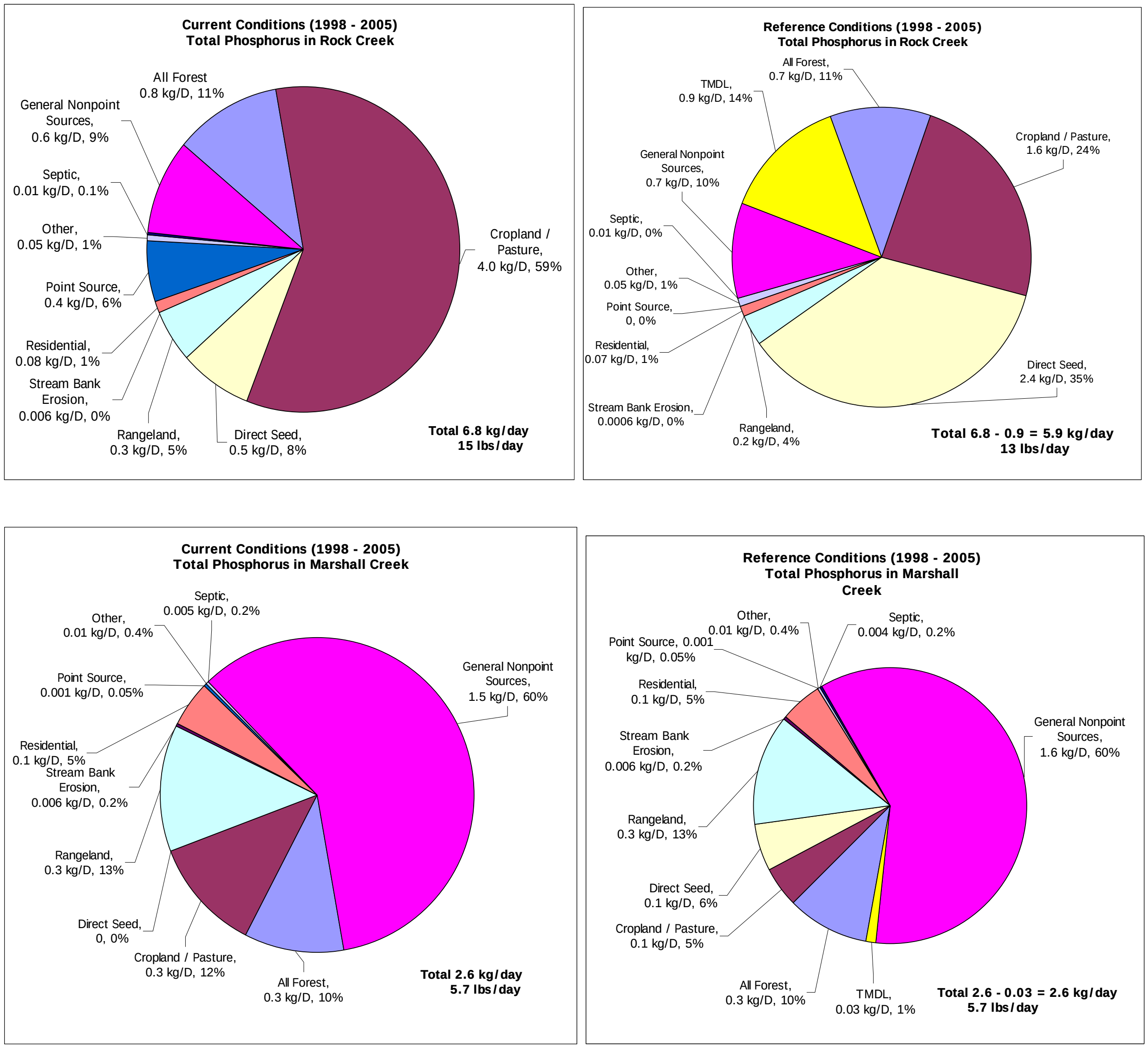


Figure P17. A comparison of estimated daily average total phosphorus loads from various sources in the five sub-watersheds of Hangman Creek under current and best potential (reference) conditions. The sixth sub-watershed has been previously shown in Figure P14.

Point Source Waste Loads

Six municipal wastewater treatment plants and three stormwater jurisdictions require phosphorus wasteload allocations on the Washington side of the border:

- Cheney WWTP
- Fairfield WWTP
- Freeman School District
- Rockford WWTP
- Spangle WWTP
- Tekoa WWTP

- Spokane County Municipal Stormwater
- Washington Department of Transportation Stormwater
- City of Spokane Municipal Stormwater

The WARMF model simulations suggest that effluent from the WWTPs generates 4.6 kg TP/day (Table P5) and contributes 8% of the annual average total phosphorus load from Hangman Creek to the Spokane River (Figure P14). Tekoa and Spangle WWTPs were built into the current condition simulation as continuously discharging facilities. Seasonal discharges from Rockford, Freeman School District, and Fairfield WWTP were simulated. Cheney WWTP was simulated as a non-discharging wetland in the form of a large onsite sewage system with high quality effluent generating 0.002 kg TP/day.

Current effluent TP concentrations for these facilities average 1 – 3 mg/L according to Ecology monitoring records and sampling conducted by the SCCD (2005). Although these concentrations are in the lower end of the range for the treatment processes used, the TP loads from the point sources require reduction. As described earlier, WWTP effluent TP loads are especially important for meeting the Spokane River TMDL allocations during the June-October season.

A WARMF scenario was run with all point source effluent concentrations discharged to surface waters reduced to 0.050 mg/L year around. The results suggested that the impact on TP loading from Hangman Creek to the Spokane River would be nearly equivalent to removal of the effluents. The point sources would generate an annual estimated average 0.09 kg/day of which 0.05 kg/day (0.1% of the total in Figure 14) would be delivered to the Spokane River. However, the analysis did not consider effects of these lower TP loads on dissolved oxygen and pH within the Hangman watershed. As point source concentrations are reduced, future monitoring should carefully monitor local effects.

Seasonal land application, modification of seasonal discharge schedules, and water reuse were not simulated, but are other methods of reducing the TP load from point source discharges. The analysis suggests that municipal WWTP permits should be conditioned so that:

- Phosphorus effluent is limited to an average annual concentration of 0.05 mg/L (50 µg/L) or less.
- Cheney WWTP should continue to maintain a non-discharging wetland unless groundwater studies prove this to be ineffective treatment for phosphorus.

A schedule for meeting the phosphorus effluent concentration will be discussed with the point sources and a compliance schedule will be included in new discharge permits. More details on interim targets are provided in the *Implementation Strategy* section of this report.

Municipal stormwater loads were not specifically modeled but can be inferred from the TP loads within catchments 1, 2 and 3 that include the mouth of Hangman Creek and the lower end of Marshall Creek (Figure P7). Spokane County and the City of Spokane have jurisdiction in urbanized areas of these catchments. Residential and commercial land uses would be associated with stormwater infrastructure. Catchments 1, 2, and 3 have 50%, 14%, and 15% of their respective areas assigned to these land uses. Stormwater TP loading in these three catchments should be minimized as future residential and commercial land uses increase.

The Washington Department of Transportation (WDOT) has stormwater management responsibilities along state and interstate routes. Stormwater from Interstate 90 and US Route 195 discharge to the lower reaches of Hangman Creek (WDOT, 2007). State Route 27, 278, and 274 cross or follow Rock Creek, Rattler Run, Little Hangman Creek, and Hangman Creek from Fairfield to Tekoa. Estimating TP loads from WDOT stormwater conveyances is difficult. Road outfalls from road runoff and runoff from lands adjacent to road ditches have not been monitored in this watershed. WSDOT will need to monitor and evaluate treatment systems and the runoff quality in these areas to minimize TP loads.

Construction stormwater permits will need to comply with current regulations and limit sediment migration from sites. This TMDL evaluation and SCCD (2007) soil sampling demonstrated that watershed soils are rich in phosphorus. Sediment phosphorus can be a major source for the Spokane River from Hangman Creek.

In summary, the total phosphorus load and wasteload allocations recommended for the Hangman Creek can be summarized based on this TMDL analysis (Table P7). The allocations are based on the best potential BMPs and point source reductions in sub-watersheds. The cumulative transport from upstream sources is considered in the allocations at points along the Hangman Creek mainstem, and within tributaries.

Three areas of the allocations require further policy and technical decisions for successful application of the TMDL:

1. Recommendations for cross-border allocations will need to be negotiated with the Coeur d'Alene Tribe and State of Idaho. Spokane River TMDL allocations cannot be met without their participation.
2. The allocations should meet the seasonal Spokane River TMDL allocations for June-October. The seasonal Spokane allocations for April-May require better definition of natural conditions and interpretation of NPS allocation to meet the net 0.2 mg/L DO loss limit in Lake Spokane under critical conditions.
3. Areas within the Hangman Creek watershed may need more stringent load allocations if DO and pH require further reductions of phosphorus.

Table P7. A summary of current total phosphorus (TP) loads, and recommended load and waste load allocations (WLA) for sub-watersheds and point sources in Hangman Creek. Analyses are based on long-term daily average loads over a period of seven water years with a variety of flow regimes.

Hangman Creek Sub-watershed or Point Source	Current Load lbs TP/day (kg TP/day)	WLA or Load Allocation lbs TP/day (kg TP/day)	Target Reduction (%)
Hangman Creek at State Line	22 (10)	16 (7.3)*	26%
Tensed WWTP	2.7 (1.2)	0.04 (0.02)*+	98%
Hangman Creek from Tekoa to Bradshaw Road & Little Hangman	47 (21)	36 (16)	23%
Little Hangman at State Line	15 (6.8)	13 (6.1)*	10%
Tekoa WWTP	5.7 (2.6)	0.11 (0.05)+	98%
Hangman Creek from Bradshaw to Duncan Road and Gage	61 (28)	47 (21)	23%
Fairfield WWTP	1.7 (0.76)	0.03 (0.01)+	98%
Spangle	0.32 (0.15)	0.004 (0.002)+	98%
Rock Creek at Mouth	15 (6.8)	13 (5.9)	14%
Rockford WWTP	0.98 (0.44)	0.02 (0.009)+	98%
Freeman School District WWTP	0.002 (0.001)	0.002 (0.001)	-
Rock Creek at State Line	12 (5.6)	11 (5.0)*	10%
Marshall Creek at the Mouth	5.7 (2.6)	5.7 (2.6)	1%
Cheney WWTP	0.004 (0.002)	0.004 (0.002)	-
Spokane(City & County) stormwater	0.28 (0.13)	0.28 (0.13)	-
Hangman Creek at Mouth	101 (46)	78 (36)	20%
City of Spokane, County, and WA Dept. of Transportation stormwater	3.2 (1.5)	3.2 (1.4)	-

* Allocations and WLA for areas outside of the State of Washington jurisdiction are shown for demonstration purposes.

+ Estimate based on total phosphorus effluent concentration of 0.05 mg/L (50 µg/L).

Conclusions and recommendations

The following conclusions and recommendations are based on this total phosphorus TMDL evaluation:

- Total P and orthophosphate phosphorus (OPO_4-P) concentrations at the mouth of Hangman Creek have declining trends over the past 10 years (1995 – 2005). However, streamflows have dropped over the same period.
- Phosphorus concentrations are significantly correlated with streamflow and sediment concentrations in Hangman Creek.
- Approximately 35% of the land area of Hangman Creek lies within the Coeur d'Alene Reservation and Idaho, and 60% of the average annual streamflow comes from there.
- Total phosphorus loads from Hangman Creek are of greatest concern to Spokane River/Lake Spokane water quality in the months of April, May, and June. Streambank and upland

erosion from agricultural lands during storm and snowmelt events are major sources at that time.

- The estimated load capacity for Hangman Creek in April and May is less than the recommended Spokane River/Lake Spokane TMDL load allocations. Spokane River model adjustments to higher TP natural conditions may bring the two estimates into better agreement.
- Point sources in the Hangman Creek watershed deliver significant TP loads, especially during the low-flow months.
- Model results confirm that phosphorus generated in upper Hangman Creek and in Idaho may take years to reach the Spokane River because of long periods of settling in intervening channels until a scour event of high enough intensity and duration can move it downstream. Some phosphorus also is taken-up into the aquatic community as plant and animal life with varying life spans.
- Day to day TP concentration and streamflow variability will be a problem for compliance assessment. The sudden onset of storm and run-off events can radically change monthly and seasonal average loads depending on whether or not they are part of the sample set.
- Future model development will require additional data:
    - Precipitation data from several areas within the watershed.
    - Continuous streamflow and routine phosphorus monitoring at major tributaries and points along the mainstem.
    - Better phosphorus and effluent discharge data from WWTPs and stormwater point sources
    - Soil-water phosphorus concentrations from various ecoregions in the watershed.
    - Rates, spatial and seasonal distribution, and biomass estimates of aquatic macrophytes and periphyton within the watershed.
    - Erosion rates from streambank and upland areas of the watershed.
    - The number of systems and rates of on-site septic failure in various sub-watersheds.
    - Data on the soluble phosphorus fraction of the total phosphorus load at various sites in the watershed.
- Spokane River and Lake Spokane dissolved oxygen responses to Hangman Creek TP loads under higher streamflow conditions have not been evaluated, but may be necessary to fine-tune the Hangman Creek allocations. In the meantime, the April – May seasonal load allocation for Hangman Creek under low-flow conditions should be re-evaluated in cooperation with the Spokane River and Lake Spokane DO TMDL work using the CE-QUAL-W2 model.
- Many implementation measures for this and the other TMDLs in the watershed will help to reduce TP, and help reduce DO and pH criteria violations.

Allocation for future growth

Future growth is included in the best potential future scenario as estimated residential growth in the three catchments closest to the mouth of Hangman Creek. These catchments are in the urban area of the watershed and considered the most likely areas for growth. Growth in this case being the conversion of agriculture, forest, and range lands to residential uses. The small municipalities and communities in the watershed are not expected to experience significant growth in the 5-10 year time-scale of this TMDL evaluation.

The future growth allocation is primarily included as increased residential and accompanying stormwater TP loading. It is not set aside. Spokane County, City of Spokane, and Washington Department of Transportation are required to limit pollutant discharge in stormwater using best management practices.

Margin of safety

The federal Clean Water Act requires that Total Maximum Daily Loads (TMDLs) be established with margins of safety (MOS). The MOS account for uncertainty in the available data, or the unknown effectiveness of the water quality controls that are put in place. The MOS can be stated explicitly (e.g., a portion of the load capacity is set aside specifically for the MOS). But, implicit expressions of the MOS are also allowed such as conservative assumptions in the use of data, application of models, and the effectiveness of proposed management practices.

Implicit margin of safety factors were included in the development of the total phosphorus load allocations:

- The models consider long-term transport of phosphorus from the entire Hangman Creek watershed without regard to distance or political borders.
- The allocations include periods of time (1998 – 2000) before improvements were made in the watershed to reduce upland and streambank erosion, and before some WWTP improvements.
- Conservative erosion, land use, and initial condition terms were used in the WARMF model.
- The best management practices simulated to develop load allocations are progressive and involve considerable changes in land use practices and source management.

Turbidity and total suspended solids

Areas of concern

Turbidity and suspended solids have been longstanding problems in Hangman Creek. In 1980 and in 1988, Hangman Creek Water Quality Index scores were among the worst in the state for turbidity and suspended solids (Singleton and Joy, 1981; Hallock, 1988). Naturally erosive streambanks and erosive upland soils in various parts of the watershed have been further destabilized by poor road building and agricultural practices (Figure 3 and Figure SS1). The sediment and associated turbidity degrade aquatic habitats and transport excessive amounts of nutrients in Hangman Creek and the Spokane River.

According to Ecology monthly monitoring data at the mouth of Hangman Creek, suspended sediment concentrations and turbidity have decreased over the past 10 years (Figure P3 and Figure SS2). Lower than normal discharge volumes are partly the cause, but channel restoration efforts and improved riparian practices have also helped reduce sediment transport (SCCD, 2002). Some farmers have switched to less erosion-prone crops or have gone to more conservation-minded methods of farming. But there is some fear that recent market economics may encourage farmers to use land previously considered marginal or set aside for stream buffers.

Previous analyses of bed and suspended sediment loads by USGS and SCCD (SCCD, 2002) have shown wide variability depending on annual streamflow volumes and characteristics (Table SS1). The evaluation also stated that most bed load is from the lower reaches of the Hangman watershed, whereas both the upper and lower reaches contribute to the suspended sediment load.

Table SS1. Annual sediment discharge estimates from sample collected at the mouth of Hangman Creek by the USGS and SCCD from 1997 through 2001 (SCCD, 2002).

Water Year	Annual Suspended Sediment Load (tons)	Annual Bed Load (tons)	Annual Total Sediment Load (tons)	Annual Average Discharge (cfs)
1998	35,200	5,100	40,300	166
1999	175,000	14,000	189,000	315
2000	83,000	12,300	95,300	273
2001	3,430	1,310	4,740	83.7

Figure SS1. An example of bank erosion in an agricultural area of Hangman Creek.

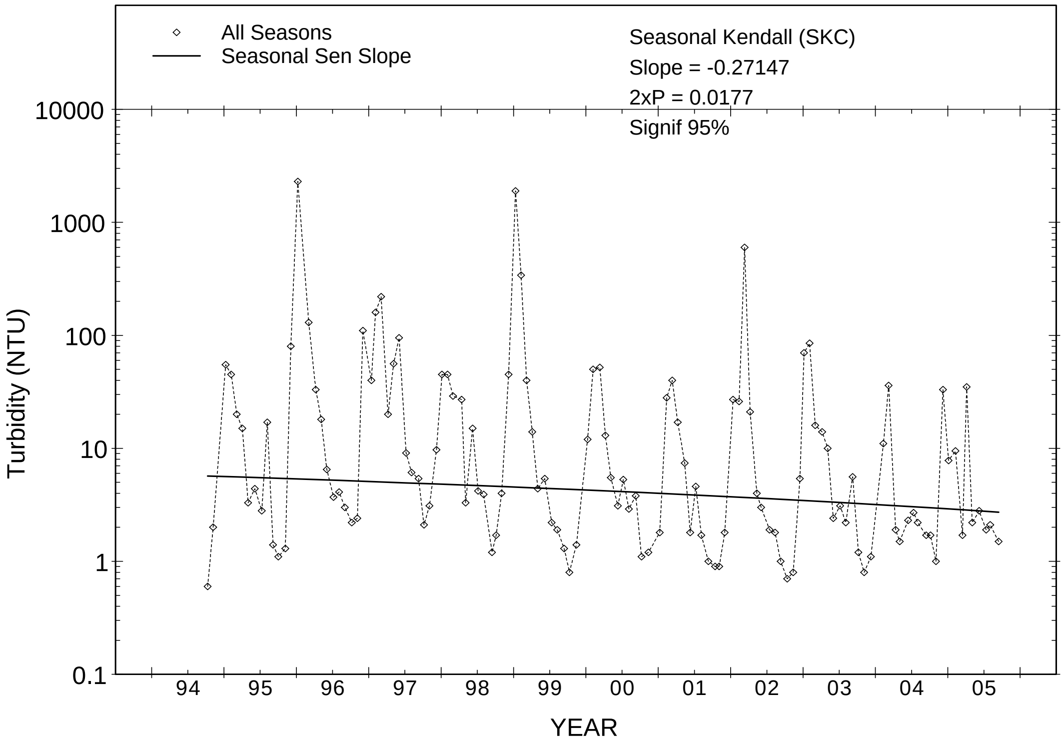


Figure SS2. The turbidity trend from 1994 – 2005 from monthly samples in Hangman Creek at Ecology station 05A070.

Four areas of Hangman Creek have been listed for turbidity criteria violations (Table SS2). The listings are based on work performed by the SCCD in 1994 through 1997 (SCCD, 1999). The turbidity criteria were applied to all the sites based on the turbidity at the most upstream site in the study, Hangman Creek at the Idaho state line. A strong relationship between total suspended solids (TSS) and streamflow was observed. So, the median turbidities were calculated when flows were above or below 100 cfs, 12.5 NTU and 50 NTU, respectively (SCCD, 1999). Turbidities at other sites in the project area were compared to allowable maximums of 17.5 NTU and 55 NTU.

Table SS2. Areas of Hangman Creek on the 2004 303(d) list for turbidity.

Waterbody	Parameter	Listing ID	Section, Township, Range
Hangman Creek at Bradshaw Rd	Turbidity	40942	Section 16 T22N R44E
Little Hangman Creek	Turbidity	40940	Section 13 T20N R45E
Rattler Run Creek	Turbidity	40941	Section 16 T22N R44E
Rock Creek	Turbidity	40943	Section 23 T23N R44E

The procedure for the listing the areas in Table SS2 are not totally appropriate. The listing rightly calls attention to the serious problem of sedimentation throughout the Hangman watershed. But, it mainly demonstrates the difficulty in addressing turbidity and suspended sediment issues using the state turbidity standards and will not be able helpful for developing a TMDL. The criteria are best applied to a single point source with a single reference location just upstream. The criteria have been successfully applied to a large irrigation project with a single source of water, distributed for irrigation, and returned downstream where the effect can be measured without other significant sediment sources (Joy and Patterson, 1997).

In contrast, only the Hangman Creek Bradshaw (listing 40942) receives water directly from the Idaho state line site, but it also is downstream of Little Hangman Creek. Little Hangman, Rattler Run, and Rock Creek are all tributaries that deliver water to Hangman Creek below the Idaho state line, but some sites are in different ecoregions with different soil and vegetation characteristics. Drainage areas and land uses are of different sizes, too. There is no single water source or set watershed characteristics to be a reference for the four 303(d) listed water bodies.

Intensity and duration of turbidity and suspended sediment are important factors to consider for aquatic life effects. Cold water aquatic organisms in the Pacific Northwest have evolved to tolerate various concentrations of suspended sediment of short duration. Extreme concentrations or long periods of intense or elevated suspended sediment can permanently change community structure and behavior. The state turbidity criteria do not address duration or extreme conditions.

Fish and benthic macroinvertebrate populations are especially sensitive to the direct and indirect effects of sedimentation and turbidity. Elevated suspended sediment concentrations suffocate salmonid eggs buried in redds, and sweep-out and smother macroinvertebrates. Channel filling eliminates pool habitats and shallow depths are prone to quicker heating to lethal temperatures. High turbidities can cause behavioral changes in fish communities. Some toxic and oxygen-demanding chemicals are adsorbed to settled sediment where they are available to harm organisms.

Benthic macroinvertebrate evaluations in 1995-7 (SCCD, 1998) and in 2003 (Ecology, 2007) identified several reaches with benthic community impairment. SCCD (1998) identified Hangman Creek at Roberts Road and at Bradshaw Road as having the most impaired habitat and macroinvertebrate communities among six sites evaluated. Ecology (2007) data (Table SS3) had similar macroinvertebrate scores except the Ecology scores for the site at the mouth of Hangman Creek were lower than given in the assessment by SCCD (1998).

There are many concerns about wide-spread problems with suspended sediments and turbidity in the Hangman Creek watershed:

- Suspended sediment can transport phosphorus and other pollutants,
- Suspended sediment and turbidity degrade aquatic communities and their habitats
- Channel-filling and bank erosion in Hangman Creek are problems aggravated by increased suspended sediment transport
- Spokane River dams are experiencing accelerated pool sedimentation downstream from Hangman Creek loads, and
- Sediments export pollutants from Hangman Creek to the Spokane River.

Table SS3. Benthic macroinvertebrate sample scores from seven sites in the Hangman Creek watershed collected August 11 – 14, 2003 (Ecology, 2005).

Site	Overall Score	Long-Lived Score	EPT Score
Hangman Creek at Mouth	24	3.3	10.8
Hangman Creek at Bradshaw Road	26	3.3	12.5
Hangman Creek at Tekoa	20	3.0	9.3
Marshall Creek	32	5.5	16.5
California Creek near Mouth	36	5.8	19
Rock Creek at Jackson Road	26	2.3	10.3
Rattler Run near Mouth	28	3.0	9.3

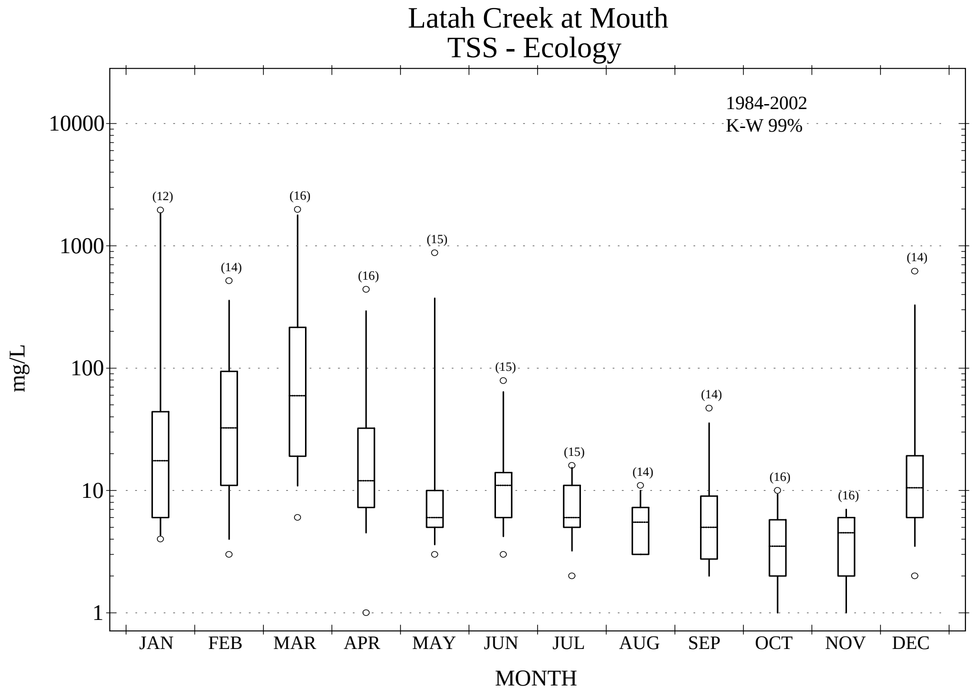
Overall Score = sum of ten indices: > 34 good, 23 – 33 fair, < 22 poor
Long-lived score = average number of long-lived taxa
EPT Score = average number of taxa in the orders Ephemeroptera, Plecoptera, and Tricoptera

Critical conditions

Elevated suspended sediment and turbidity have been most pronounced in the months of January through March (Figure SS3). A previous evaluation of total sediment transport by USGS and SCCD (2002) came to the same conclusion. These are also the months with the highest mean monthly discharge (Table HC1). During this period, conventionally tilled fields are susceptible to erosion by rains falling on partially frozen and snow-covered soils with little residue (SCCD, 2002).

Wastewater treatment plants are not considered significant sources of turbidity and solids in Hangman Creek. Current municipal NPDES permits limit total suspended solids to loads far lower than are of concern in the watershed – annual averages of pounds/day compared to tons/day for some land uses. Municipal and construction stormwater sources are potentially sources during storm events. However, construction stormwater permits are written to limit turbidity levels to less than 25 NTUs.

TSS and turbidity are somewhat correlated with discharge. Storm events any time of the year with a rapid rise in stage height also generates elevated levels of turbidity and suspended sediment. This was observed over the 1998-2001 USGS and SCCD cooperative monitoring period during several events (SCCD, 2002), and during the 2003-2004 monitoring surveys (SCCD, 2005).



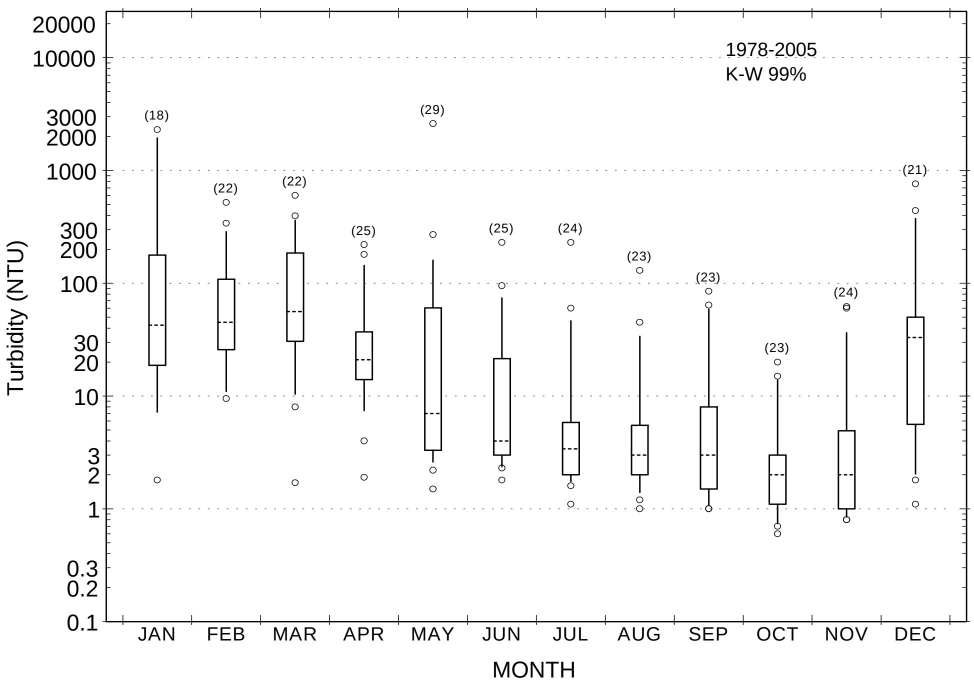


Figure SS3. Total suspended solids (TSS) and turbidity statistics from monthly samples collected at the mouth of Hangman Creek from 1984 to 2002. The box plots show the 90th and 75th percentile, median, 25th and 10th percentile. In parenthesis are the sample counts used to generate the statistics.

Transport of phosphorus associated with the suspended sediments to the Spokane River is of greatest concern in April through June. However, as described in the phosphorus section of this report, the transport of sediment and other materials from the upper watershed can take from days to years depending upon the hydrologic characteristic of the season and the distance from the mouth of the creek. Therefore, a multi-year analysis is appropriate.

A multi-season, multi-year analysis also makes sense from a biological viewpoint. Sensitive life-stages of fish and benthic macroinvertebrates are present at various times of the year. Organisms and their habitat are damaged by both the intensity and duration of suspended sediment/turbidity. The purpose of the TMDL will be to limit the intensity and duration of turbidity/suspended sediment events in the watershed.

Analytical framework

Data collected by Ecology, SCCD, and USGS were used to evaluate the relationships between total phosphorus, TSS, and turbidity in Hangman Creek. Movement of suspended sediments or TSS is often associated with rapid streamflow changes. Suspended sediments are part of the matrix of soil, sediment, or organic solids particles carried from uplands, streambanks, and stream bottoms. Fine sediments can also be blown by winds into waterways and drainage routes.

Turbidity is regulated under the state water quality standards with specific criteria; suspended sediments are not. But, turbidity loads cannot be calculated since turbidity is a measure of visibility through water, not a concentration of something in the water. That is why a surrogate measure is needed to conduct a TMDL for turbidity.

Turbidity and suspended solids are often correlated in the water column since more solids will scatter more light, reduce visibility, and increase turbidity. So, TSS often is used as a surrogate to calculate loads that are converted to turbidity units that can be compared to criteria.

The Hangman Creek data show some challenges for using turbidity to estimate TSS (Figure SS4). Turbidity measurements rely on particles remaining in solution. If the TSS particles sink or float, the correlation between the turbidity and suspended solids becomes more variable. This especially occurs during high streamflow events when heavier sands and lighter organic debris are swept in the current. The TSS method uses only a portion of the entire sample collected. Heavier and lighter materials can be left out of the portion of the sample that is drawn and analyzed.

Ecology laboratories used a different type of turbidimeter after September 1993. The ratio turbidimeter used since then allows correction for back-scatter. The relationship between turbidity to TSS is linear over a wider range of values with the correction. The turbidity and TSS content of samples collected at the mouth of Hangman Creek show some relationship within distinct ranges of values (Figure SS4).

The shift in the relationship between TSS and turbidity at 10 mg/L TSS and again at 500 mg/L TSS in Figure SS4 may be a result of any combination of the analytical problems mentioned. Sediment particles from different soil types in the watershed arriving at the mouth of the creek at different times can also increase the variability in the TSS to turbidity relationship.

The turbidity criteria are difficult to establish for a site in a watershed when nonpoint sources and natural events are the dominant factors of interest. A reference turbidity value is required to measure against turbidity increases at the point of interest. In a watershed with several soil and land use types, an adequate reference site, or set of reference sites, is difficult to obtain. The Washington/Idaho border site used to promote sites in the watershed to the 303(d) list is inadequate for the reasons mentioned earlier. Therefore, the TMDL will not be based on turbidity measurements, but on reductions of suspended sediment.

However, the evaluation of TSS and suspended sediment is not without difficulties. The sample collection and analysis of TSS is different than for suspended sediment. The differences are important for comparing data and calculating loads. For suspended sediment, several samples are collected through the entire water column and across the width of the stream. Each one is analyzed by using the whole sample and these are summed to derive the suspended sediment load. TSS samples are single depth collections with only part of the sample drawn for analysis. The differences in technique usually result in TSS concentrations underestimating suspended sediment loading during moderate and high streamflow events.

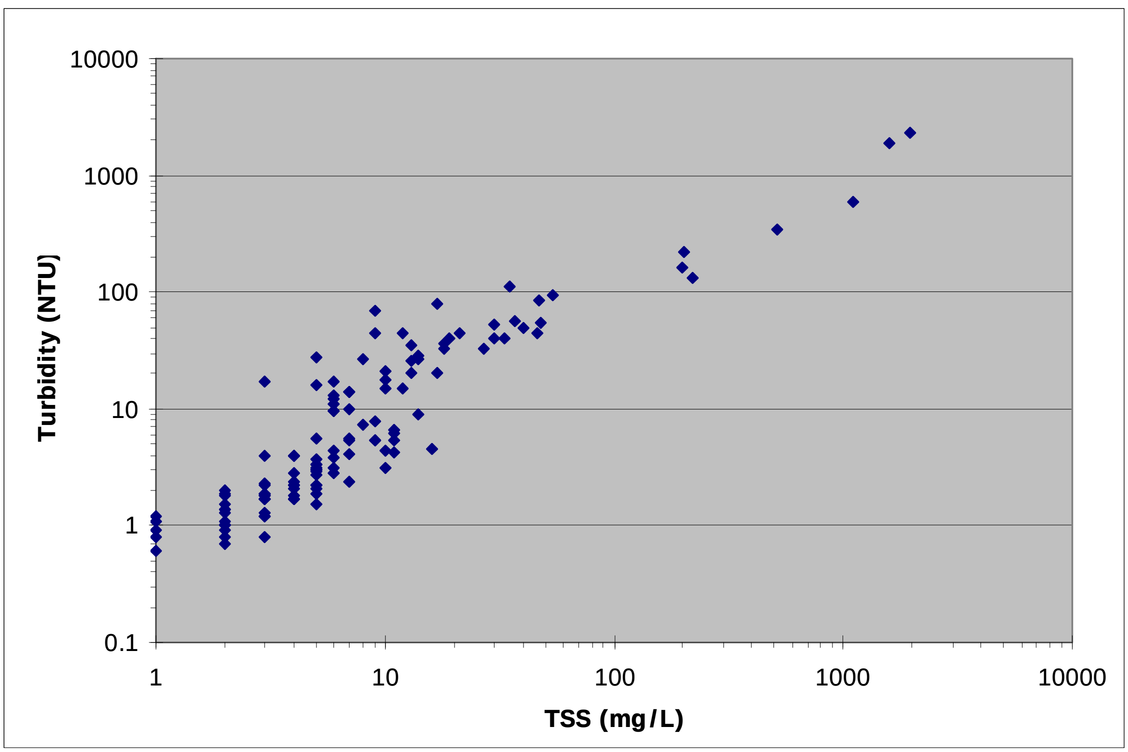


Figure SS4. Total suspended solids (TSS) concentrations compared to turbidity results in monthly samples collected at the mouth of Hangman Creek (56A070) from October 1994 to September 2005.

The TSS/suspended sediment data analysis follows the procedures previously described in the phosphorus TMDL section. Statistical tests were run using WQHYDRO (Aroner, 2007) and Microsoft® Office Excel (2003) software. Multiple regression analyses were run using a method by Cohn (2002) with SYSTAT software. The Watershed Analysis Risk Management Framework (WARMF) model was also used to evaluate landscape and water column loads of TSS in the entire Hangman Creek watershed. The model was constructed and calibrated for the Hangman Creek watershed by the Cadmus Group and CDM (2007).

The WARMF model was used to evaluate the relative impact of landscape and water column TSS loads in the entire Hangman Creek watershed (Washington, Coeur d'Alene Reservation, and Idaho). The USEPA Region 10 office provided a grant to perform the work. The USEPA, Coeur d'Alene Tribe, Ecology, and SCCD agreed that an assessment of the whole watershed was necessary. The model was constructed and initially calibrated for the Hangman Creek watershed by the Cadmus Group and CDM (2007).

CDM (2007) divided the watershed into 36 catchments in the model to characterize hydrology and pollutant delivery (Figure P7). Local soils, land uses, climate, and geographic features of the land and stream channels are generalized within each of the 36 catchments of the WARMF model. The average size of the catchments was 12,000 acres with a range of 576 acres to 27,785 acres. Model outputs are calculated daily based on rainfall, temperature, and point source inputs. Descriptions of the model and coefficients of interest are provided in the total phosphorus section and Appendix X.

The goal of the framework will be to estimate the suspended sediment/TSS reductions that can be expected after a progressive set of best management practices are in place. The reductions will be estimated for the mouth of Hangman Creek, for 303(d) sites, and for other critical tributary sites in the watershed. Turbidity criteria can be used in the future if proper upstream reference sites are characterized for short reaches of interest. An example would be compliance or effectiveness monitoring at a point source or substantial nonpoint best management improvement project.

Calibration of model

The long-term monthly TSS data record collected by Ecology at the mouth of Hangman Creek (Station 56A070) provides a calibration dataset for the Hangman Creek models. However, the dataset has some of the limitations as for phosphorus data:

- Samples collected by Ecology at the site are not laterally or transversely integrated, so they may under-represent the true average suspended solids concentration and load.
- It does not record rapid changes in discharge and TSS concentrations within a day.
- Watershed land uses, and crop rotation and management patterns have changed. So, consistent statistical relationships between season, streamflow, and TSS cannot be assumed.

The multiple regression equation was applied to the monthly TSS concentrations collected by Ecology, and the mean daily streamflow reported by USGS at the mouth of Hangman Creek. The Nash-Sutcliffe coefficient was used to evaluate the model fit to observed data. The model fit the observed TSS/suspended sediment load estimate very well (Figure SS5) and even when the USGS suspended sediment data are added (Figure SS6). The Nash-Sutcliffe coefficient of observed Ecology data and model output is 0.8, where 1.0 is ideal.

The same Watershed Assessment Risk Management Framework (WARMF) model was used to evaluate suspended sediment and total phosphorus in the Hangman Creek watershed. The model calibration procedures and adjustments to the original model received from CDM (2007) were previously described in the total phosphorus section. The WARMF model was calibrated to the USGS and SCCD suspended sediment data collected at the mouth of Hangman Creek from 1998 to 2001 in addition to the Ecology monthly TSS data. As mentioned earlier, these data are not quite equivalent and combining them into one database may increase model variability.

Only a few suspended sediment or TSS data were available at other sites in the watershed. The majority of suspended sediment data were collected by SCCD (1999) before the model calibration period of 1998 to 2005. The SCCD (2005) TMDL surveys from December 2003 to August 2004 supplied a few suspended sediment data for model calibration at various sites in the watershed.

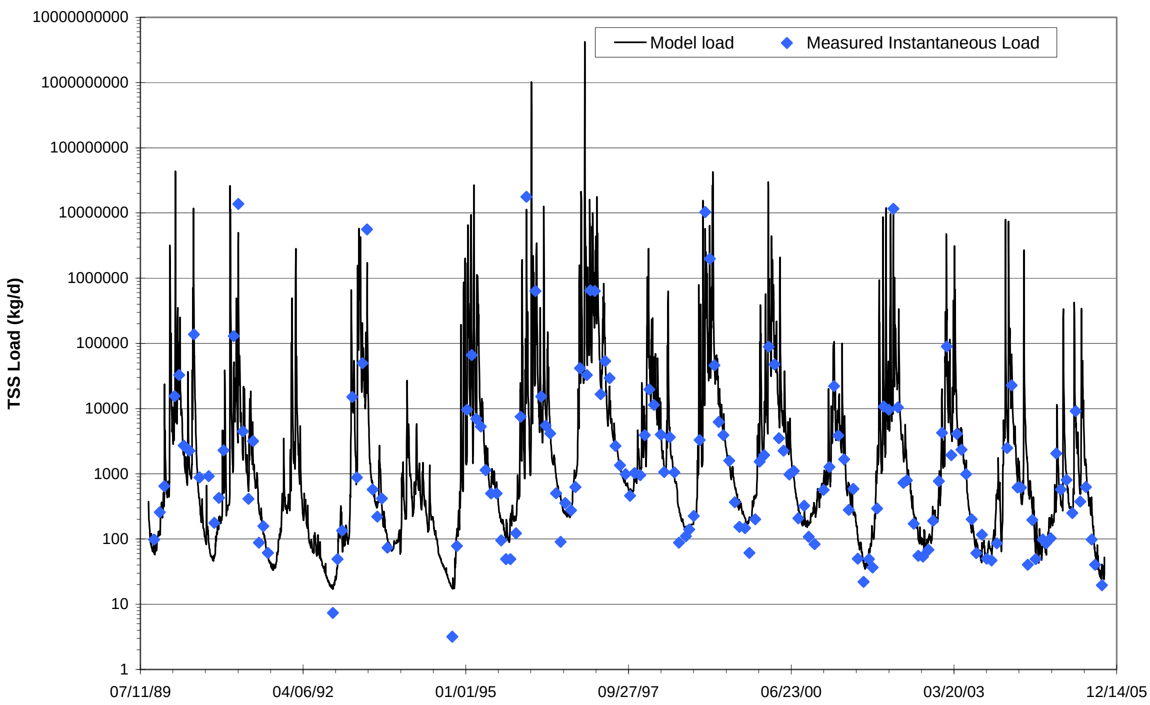


Figure SS5. Total suspended solids (TSS) estimated loads in kilograms per day (kg/d) from the multiple regression model compared to TSS estimated loads based on monthly TSS samples and instantaneous discharge measurements collected at the mouth of Hangman Creek (Ecology station 56A070).

The WARMF model suspended sediment output (Figure SS 6) shows some of the same characteristics as the phosphorus output did (see Figure P10). As mentioned in the total phosphorus model discussion WARMF hydrology simulation tended to overestimate low streamflows and create high streamflow spikes, especially during low streamflow years. These become more exaggerated when the model simulates suspended sediment load because of the uncertainty in erosion rates and transport coefficients.

The overall annual load estimated by the WARMF model is greater than calculated by SCCD (2002) or the multiple regression model for the years 1998 to 2005 (Figure SS 7). Higher streamflow years like 1999, 2000, and 2002 are simulated a little better than low streamflow years. Higher flow months match a bit better than transition (fall, late spring) or low streamflow months, but the relationship between discharge and TSS is different even at flows greater than 100 cfs (2.83 cms) Figure SS8. The WARMF model is biased high relative to the multiple regression model and has a higher variability.

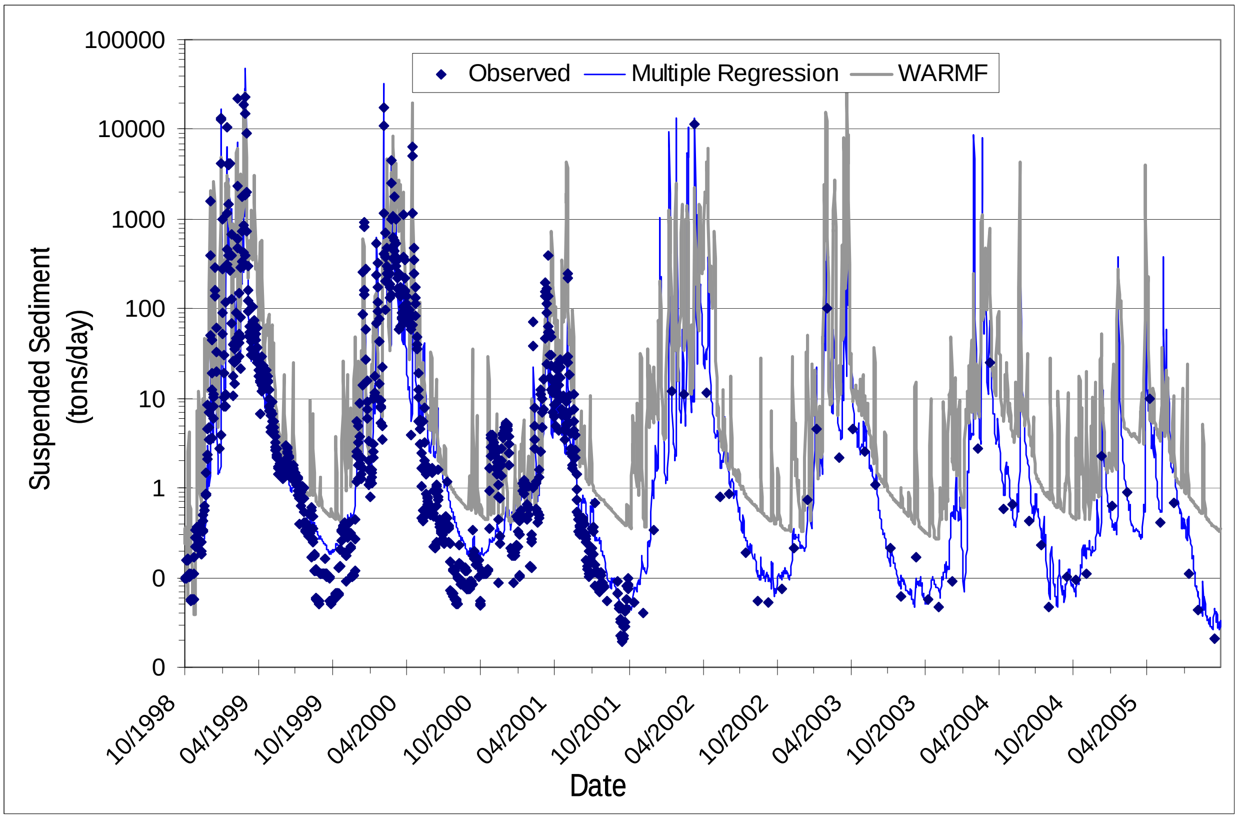


Figure SS6. A comparison of suspended sediment loads from WARMF and the multiple-regression models output, and observed (adjusted) instantaneous loads for the mouth of Hangman Creek.

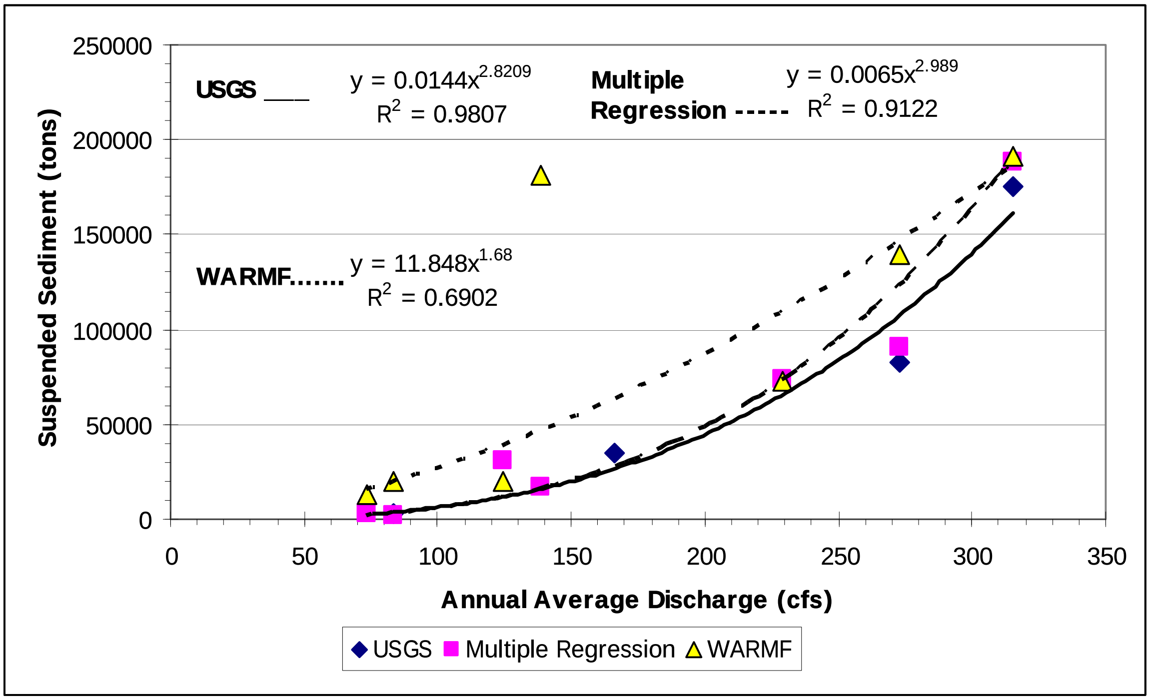


Figure SS7. Three estimates of annual suspended sediment load compared to annual average discharge at the mouth of Hangman Creek for the water years 1998-2005.

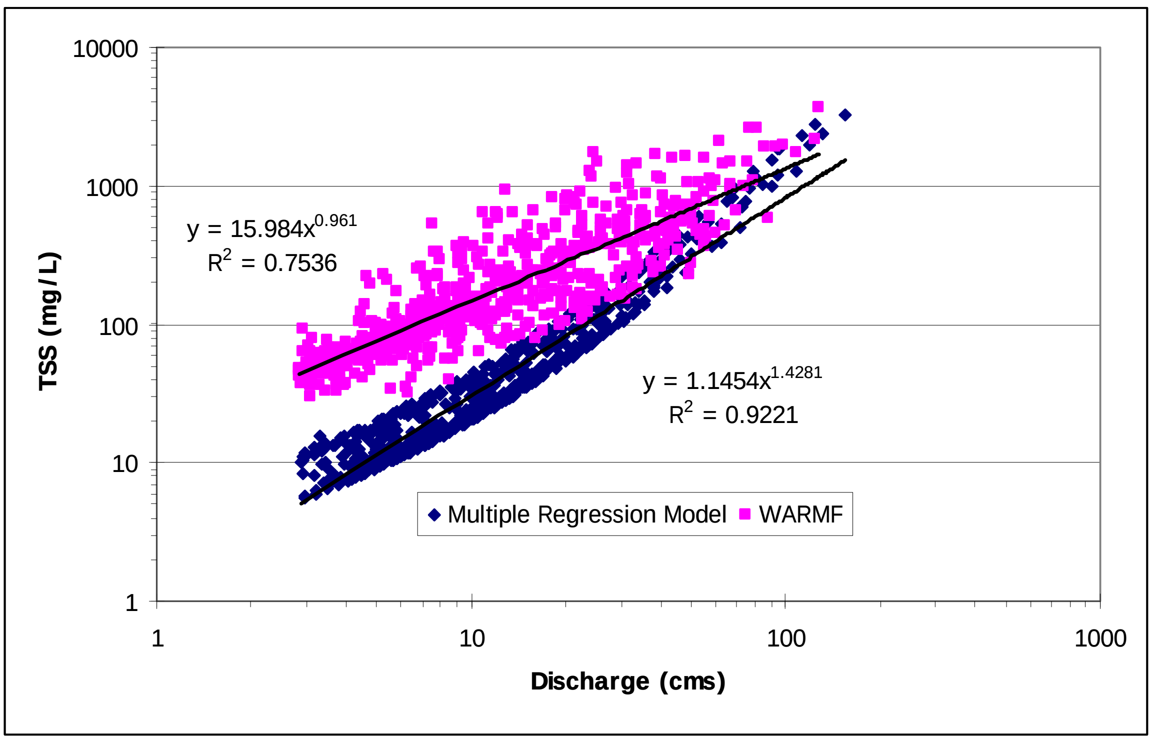


Figure SS8. Hangman Creek at the mouth: correlation between discharge and suspended sediment concentration estimated by two different models for discharges greater than 2.38 cubic meters/second (cms) = 100 cubic feet/second.

Loading capacity

Developing an estimate of the suspended sediment loading capacities for Hangman Creek and its tributaries is a difficult task. The watershed encompasses no less than four Level IV Ecoregions with different geological and vegetation characteristics. The morphology of the watershed is a result of centuries of erosive forces on natural sources of sediment. Added to these natural processes are human practices over the past 150 years that have accelerated some forms of sediment transport.

There are no clear numeric targets for TSS or suspended sediment to set loading capacities. And, as discussed earlier, the turbidity criteria have limited use in the context of watershed erosion problems. Some states mandate soil erosion tolerance levels for agricultural lands, but Washington has not established these measures. Other states have sedimentation criteria for spawning habitat or other aquatic habitat metrics. These have not been established in Washington either.

By reducing the duration and frequency of elevated turbidity and TSS events through erosion control measures, a ‘flattening’ of the annual average discharge to sediment delivery relationship curve should occur (Figure SS7). Benthic macroinvertebrate and aquatic habitat metrics should also gradually improve in impaired reaches (Table SS3). A reference set of these metrics has not yet been established for the ecoregions of Hangman Creek. The variable nature of TSS and turbidity and the application of these indirect measures of watershed health require a large data set and careful interpretation.

As mentioned earlier, the Hangman Creek Advisory Committee questioned if pollutant load capacities should be predicted from a pristine or natural state scenario that would serve to estimate a loading capacity. The following points were made:

- the stream channel and land uses have changed greatly over the past centuries of human habitation
- no reference sub-watersheds are available for each of the diverse Ecoregions represented in the watershed

Therefore, a best potential or future reference condition for the watershed was developed to represent the natural or baseline condition. The characteristics of the best potential condition were based on the following question put to the Hangman Creek Advisory Committee:

“What is the best possible set of actions that could be implemented in the Hangman Creek watershed to achieve pollutant reductions?”

The recommendations by the Advisory Committee covered a wide range of progressive actions:

- Convert 60% of the agriculture in the watershed to direct seed or conservation practices.
- Have 10 foot riparian buffers established all along the mainstem channels and tributaries.*
- Reduce the streambank erosion in the upper watershed (above Fairfield) by 50% and erosion in the lower watershed with Lake Missoula flood sediments by 10%.

- Increase forest cover in catchments above Rockford and Tensed by 50%.
- Limit residential growth to levels below 10% in lower watershed (catchments 3, 4, 7, 9 and 10).
- Eliminate point source discharges to surface water.
- Repair failing residential on-site septic systems.

*Although the Natural Resource Conservation Service (NRCS) requires 35 feet buffers under their funding programs for establishing new buffers, the advisory committee felt 10 foot buffers throughout the watershed was a more accurate estimate of what could be achieved watershed-wide. Some stream reaches may have buffers greater than 35 feet, while it may be difficult to establish any buffer in other areas.

Most of the recommended actions would significantly reduce sediment transport in the watershed. The conversion of conventional to conservation agriculture methods, developing riparian buffers, and stabilizing streambanks would be especially helpful. As with the phosphorus analysis, these actions were seen as very aggressive, long-term, and highly intensive in terms of watershed cooperation and management.

The calibrated WARMF model was used to estimate the effect of this set of best management practices (BMPs) to reduce suspended sediment in Hangman Creek (Figure SS9). Although the WARMF model calibration of observed sediment data is not as closely matched as the multiple regression model, the results provide important insight into the response of sediment sources in the watershed to actions. *The best potential scenario of BMPs is considered an estimate of the reference turbidity and suspended sediment loading conditions, and represents the loading capacities for Hangman Creek and various areas in the watershed.*

The estimated annual suspended sediment loads under the best potential scenario are 20% to 30% lower than the simulated current condition (Table SS4). The annual variability is induced both by the intensity and frequency of runoff events and location of those events within the watershed. Years with higher annual flows will also generate more streambank erosion in the lower reaches that are not easily remedied even under the best potential scenario actions.

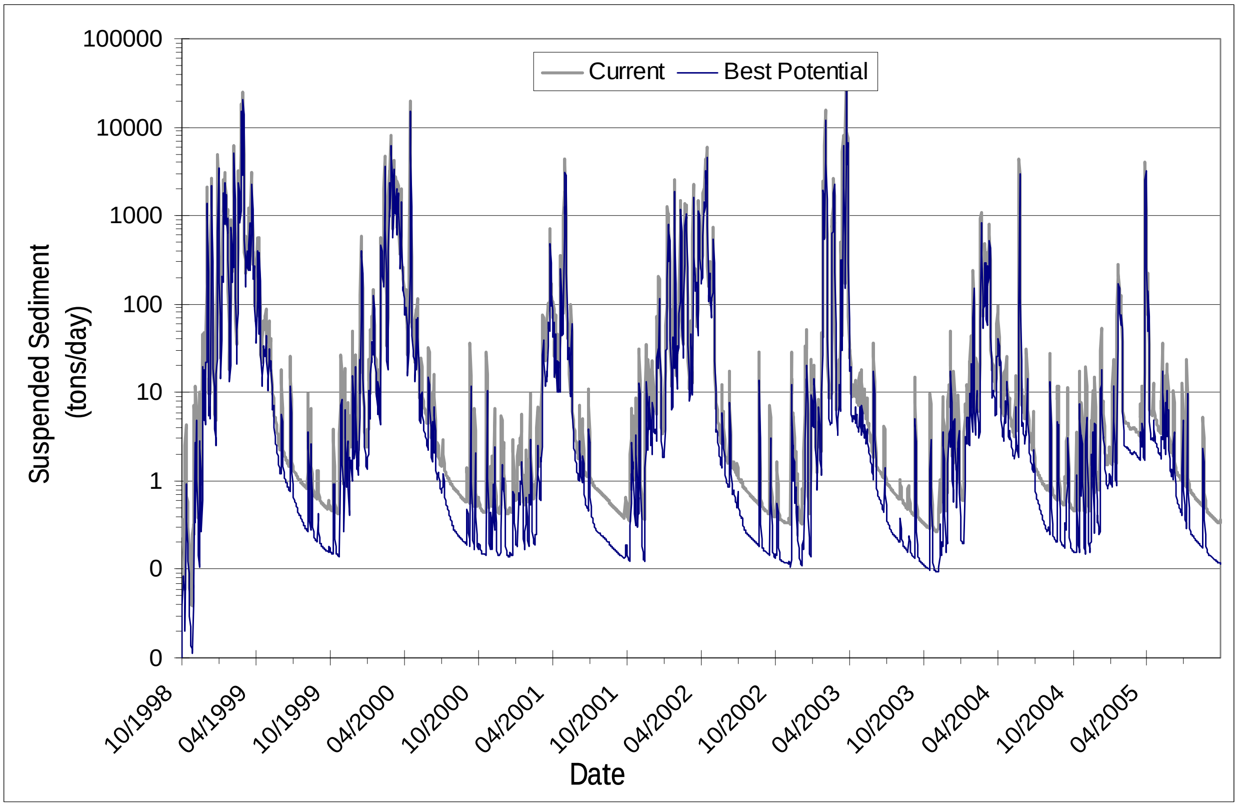


Figure SS9. Estimated daily average suspended sediment loads at the mouth of Hangman Creek based on WARMF model scenarios of current conditions and best potential future conditions.

Table SS4. Suspended sediment reduction predicted from WARMF model scenario estimates for annual suspended sediment loading from Hangman Creek to the Spokane River. WARMF model current and best potential scenario condition results were compared. The percent reduction in suspended sediment loading is applied to the regression model estimates in Table SS4 to provide an estimate of the annual load capacity.

Water Year	Multiple Regression Model (tons/year)	Estimated Reduction	Estimated Load Capacity (tons/year)
1999	188,252	22%	147,206
2000	90,677	25%	67,872
2001	1,604	31%	1,109
2002	73,770	28%	53,326
2003	16,503	21%	13,101
2004	30,605	32%	20,846
2005	2,832	29%	2,022

The total suspended sediment load at the mouth of Hangman Creek is of interest for cumulative loading from the watershed to the Spokane River, but other areas of the watershed are of interest as well. Upper watershed reaches require TMDL allocations because they are on the 303(d) list for turbidity: Hangman Creek at Bradshaw Road, Little Hangman Creek, Rattler Run, and Rock Creek (Table SS2). The SCCD and Advisory Committee consider the upper watershed sediment and turbidity problems to be more receptive to upland and streambank improvements (Figure SS1) than the eroding streambanks in the lower reaches of Hangman Creek pictured in Figure 3.

Suspended sediment loading capacities for various tributary and mainstem reaches of Hangman Creek were determined using the WARMF model scenario results. The best potential scenario provided information on land uses and streambank erosion sources of sediment. The relative difference between the current and best potential scenarios for the various areas of the watershed can help guide implementation resources and expectations.

Load and wasteload allocations

The WARMF model was used to evaluate point and nonpoint sources in the entire Hangman Creek watershed from October 1998 through September 2005. This was done in cooperation with the Coeur d'Alene Tribe and the State of Idaho at the request of Region 10 USEPA. A cooperative strategy between jurisdictions yields a more comprehensive approach to controlling suspended sediment and turbidity sources in the watershed. However, the Washington State cannot dictate to the Coeur d'Alene Tribe and Idaho what measures they need to take in Hangman Creek.

As with the phosphorus TMDL analysis, the WARMF TSS analysis is multi-year and multi-season because suspended sediment loads generated in various parts of the watershed may not affect loads to the Spokane River until months or years later. Storm intensity, duration, and frequency along with land cover, and weather conditions (e.g. frozen soils) affect rates of erosion. The rate of erosion from land and instream sources are both affected.

The average mass of sediment per day values (kilograms/day or tons/day) are a general order of magnitude approach to the problem in the watershed. The long-term averages account for the variability in weather, land cover, and hydrology. As shown in Figure SS7, the model needs more work to become better calibrated and reduce sources of variability. As more data are collected in the Hangman Creek watershed specifically, the model results should improve and provide better definition for solving the sediment erosion problems in the watershed.

The WARMF model suggested major sediment erosion generated from the same sources that have been discussed in previous reports for the watershed (SCCD, 1999; 2002; 2005a; 2005b). Conventional agricultural practices and streambank erosion are the largest sediment sources in most areas of the watershed. Table SS5 summarizes the relative distribution of sources generating sediment and the overall suspended sediment reduction for the various sub-watersheds (Figure P16) expected if the best potential activities are implemented.

Table SS5. Estimated distribution of sources generating suspended sediment in sub-watersheds of Hangman Creek under current and best potential condition scenarios and estimated source reduction expected with implementation of best potential scenario actions

Sub-Watershed	Current % of sources	Best Potential % of sources	Estimated source Reduction	Land Area % of watershed
Upper Hangman	35%	32%	26%	20%
Little Hangman & Hangman from Tekoa to Bradshaw	26%	27%	16%	19%
Hangman from Bradshaw to Duncan & Rattler Run	1%	1%	15%	8%
Rock Creek	20%	20%	18%	27%
Marshall Creek	2%	3%	8%	11%
Lower Hangman	16%	17%	11%	15%

As discussed with total phosphorus, not all of the TSS generated in the watershed during the simulation period is discharged to the Spokane River. The watershed has storage reaches and the simulation period of 1998 through 2005 generated more sediment than it delivered to the Spokane River.

Approximately 35% of the Hangman Creek watershed lies in catchments of Rock Creek, Little Hangman Creek and upper Hangman Creek in the Coeur d'Alene Indian Reservation and in Idaho (Figure P16). On average, up to 60% of the water is delivered from these catchments annually. The WARMF model estimates the cross-border average daily TSS load delivered from 1998 to 2005 in both the current and best potential scenarios are 15% - 20% larger than the load delivered to the Spokane River. Fine sediment fractions of the sediment loads generated across the Washington/Idaho border are stored in the Hangman to Bradshaw, Rock Creek, and Lower Hangman reaches.

Like the total phosphorus analysis, the best potential scenario in the WARMF model relies on conversions from range to forest and implementation of conservation farming across the border. The TSS loads from upstream catchments will need to be managed by the Coeur d'Alene Tribe and Idaho through USEPA Region 10. The substantial cross-border input of TSS and phosphorus require close cooperation to improve Hangman Creek, Little Hangman Creek, and Rock Creek.

The WARMF model output for the 303(d) listed areas was examined. Table SS6 summarizes the relative TSS reduction estimated for each area and major sources that require controls. The conversion of conventional agricultural practices to conservation practices had the largest impact because of erosion potential and upstream drainage area affected. Streambank erosion control will be important upstream of Bradshaw Road. Rock Creek actually appeared to have relatively minor TSS loads generated by streambank erosion, but restoration practices may significantly reduce them further as a TSS load source.

Table SS6. WARMF model simulation results for overall suspended sediment reductions and source reductions estimated at 303(d) sites in the Hangman Creek watershed.

Site	Overall Reduction	Primary Sources	Reduction to Sources
Hangman Creek at Bradshaw Rd	19%	Conventional Agriculture. Streambanks Rangelands	56% 74% 31%
Little Hangman Creek	15%	Conventional Agriculture	55%
Rattler Run Creek	15%	Conventional Agriculture	54%
Rock Creek	17%	Conventional Agriculture Rangelands Streambanks	55% 18% 90%

The current TSS NPDES permit limits for the six municipal wastewater treatment plants in the Washington portion of the watershed are adequate for TSS control in the watershed. As mentioned earlier, the combined WWTP loads are minor compared to the event-based loads driving field and streambank erosion. TSS wasteload allocations are equivalent to the current permit limits.

Stormwater in areas under Phase 2 and construction permits will need to be adequately managed to reduce TSS loads to lower Hangman Creek and its tributaries. The City of Spokane, Spokane County and Washington State Department of Transportation have responsibility to control stormwater in the lower reaches of Hangman Creek and Marshall Creek. The best potential scenario increased residential land use over current conditions. An estimated 7% increase in TSS generated by residential and commercial uses will require implementation of stormwater best management practices.

The WARMF modeling did not evaluate municipal stormwater management options. Best management practices for TSS in municipal stormwater are well-know and effective. The NPDES permits for these facilities should have TSS TMDL language to ensure proper characterization and maintenance of stormwater control facilities in the lower Hangman growth area.

Conclusions and recommendations

The following conclusions and recommendations are based on this suspended sediment and turbidity TMDL evaluation:

- Turbidity 303(d) listings in the watershed cannot be addressed directly because they are based on incorrect application of state turbidity criteria. The Washington/Idaho border site used to promote sites in the watershed to the 303(d) list is inadequate. Therefore, the TMDL is not based on turbidity measurements. Instead reductions of suspended sediment loads are used.
- Turbidity and suspended solids have been longstanding problems in Hangman Creek. Naturally erosive streambanks and erosive upland soils in various parts of the watershed have been further destabilized by poor road building and agricultural practices. The

sediment and associated turbidity have degraded aquatic habitats and transported excessive amounts of nutrients to Hangman Creek and the Spokane River.

- Elevated suspended sediment and turbidity have been most pronounced in the months of January through May, especially when conventionally tilled fields are susceptible to erosion by rains falling on partially frozen and snow-covered soils with little residue (SCCD, 2002).
- A best potential or future reference condition for the watershed was developed to represent the natural or baseline condition and the TSS load capacities in various areas of the watershed.
- An estimated 20% to 30% in annual TSS loads will be reduced if best potential actions are implemented.
- Conversions of conventional agricultural practices to conservation practices would have the biggest impact in reducing TSS in the watershed.
- Streambank erosion control also will help decrease sediment generation and transport especially in the reaches between Fairfield and Tekoa.
- Municipal and construction stormwater sources are potentially sources during storm events. Spokane County, City of Spokane and Washington State Department of Transportation stormwater permits in the residential growth areas in the lower reaches of Hangman Creek and Marshall will require TMDL language to ensure TSS best management practices are established and maintained.
- Wastewater treatment plants are not considered significant sources of turbidity and solids in Hangman Creek. Current municipal NPDES permits limit total suspended solids to loads far lower than are of concern in the watershed and will be adequate for wasteload allocations.

Substantial cross-border TSS loads will require close cooperation with the Coeur d'Alene Tribe and Idaho to establish erosion reduction measures and improve Hangman Creek, Little Hangman Creek, and Rock Creek.

Allocation for future growth

Municipal stormwater effects from additional residential growth in the lower Hangman watershed are included in the modeling scenarios. A growth allocation is not set aside. Spokane County, City of Spokane, and Washington Department of Transportation are required to limit pollutant discharge in stormwater using best management practices.

Growth in this case being the conversion of agriculture, forest, and range lands to residential uses. The small municipalities and communities in the watershed are not expected to experience significant growth in the 5-10 year time-scale of this TMDL evaluation. Agricultural expansion or intensity is difficult to predict. The variability in cultivation intensity from 1998 to 2005 is used to predict future variability.

Margin of safety

The federal Clean Water Act requires that Total Maximum Daily Loads (TMDLs) be established with margins of safety (MOS). The MOS accounts for uncertainty in the available data, or the unknown effectiveness of the water quality controls that are put in place. The MOS can be stated explicitly (e.g., a portion of the load capacity is set aside specifically for the MOS). But, implicit expressions of the MOS are also allowed such as conservative assumptions in the use of data, application of models, and the effectiveness of proposed management practices.

Implicit margin of safety factors were included in the development of the suspended sediment TMDL:

- The models consider long-term transport of suspended sediment from the entire Hangman Creek watershed without regard to distance or political borders.
- The allocations include periods of time (1998 – 2000) before improvements were made in the watershed to reduce upland and streambank erosion, and before some WWTP improvements.
- Conservative erosion, land use, and initial condition terms were used in the WARMF model.
- The best management practices simulated to develop load allocations are progressive and involve considerable changes in land use practices and source management.

Monitoring Recommendations

As a result of this Total Maximum Daily Load study, the following recommendations are made:

- Stormwater monitoring should include fecal coliform, temperature, phosphorus, turbidity and total suspended solids to better characterize pollutant loads coming from this source. If necessary wasteload and load allocations may need to be adjusted based on an improved understanding of stormwater pollutant loads.

- All of the WWTP facilities should monitor receiving water and effluent temperatures and discharge volumes during the spring through fall season. When the thermal and dilution cycles are better understood, compliance schedules and operational/facility options can be better designed.

- Monitoring, especially for phosphorus, should include a seasonal sampling strategy to ensure compliance with the Hangman and Spokane River TMDL targets are not misjudged.

- Improved characterization of Hangman Creek's natural conditions for phosphorus levels could refine Spokane River dissolved oxygen modeling and Hangman Creek phosphorus modeling. This data would help rectify some of the discrepancies between the two models different estimates of natural conditions.

- Future WARMF model development for phosphorus, turbidity and TSS will require additional data:
    - Precipitation data from several areas within the watershed.
    - Continuous streamflow and routine phosphorus monitoring at major tributaries and points along the mainstem.
    - Better phosphorus and effluent discharge data from WWTPs and stormwater point sources
    - Soil-water phosphorus concentrations from various ecoregions in the watershed.
    - Rates, spatial and seasonal distribution, and biomass estimates of aquatic macrophytes and periphyton within the watershed.
    - Erosion rates from streambank and upland areas of the watershed.
    - The number of systems and rates of on-site septic failure in various sub-watersheds.
    - Data on the soluble phosphorus fraction of the total phosphorus load at various sites in the watershed.

- Spokane River and Lake Spokane dissolved oxygen responses to Hangman Creek TP loads under higher streamflow conditions have not been evaluated, but may be necessary to fine-tune the Hangman Creek allocations.

- Dissolved oxygen and pH 303(d) listings were not evaluated as part of this study and will need to be characterized in the future.
- Reference sites will need to be established for distinct reaches of interest before turbidity criteria are applied

Implementation Strategy

Introduction

This Implementation Strategy describes what will be done to improve water quality. It describes the roles and authorities of cleanup partners (that is, those organizations with jurisdiction, authority, or direct responsibility for cleanup) and the programs or other means through which they will address these water quality issues. It provides a feasible and effective strategy to achieve the water quality standards for fecal coliform bacteria, turbidity, temperature, and nutrients (total phosphorus). The development of this plan was a collaborative effort by a diverse group of interests in the watershed and was facilitated by the Spokane County Conservation District.

After the U.S. Environmental Protection Agency (EPA) approves this TMDL, interested and responsible parties will work together to develop a *Water Quality Implementation Plan*. The plan will describe and prioritize specific actions planned to improve water quality and achieve water quality standards.

What needs to be done?

The Hangman Creek TMDL Advisory Committee first met in April 2004. The committee formed at the April 2004 meeting and has been meeting approximately monthly. The intent of the committee was to identify water quality issues in the watershed that are related to increased loads of fecal coliform, phosphorus, turbidity, and heat (temperature). The committee then developed a list of Best Management Practices (BMPs) that may offer one or more solutions for each issue. This report reflects the local stakeholders awareness of the water quality problems and related issues. This report was developed locally to reflect the local needs, values, and priorities.

The water-quality-related issues evaluated for the TMDL by the committee were:

- Issue 1: Sediment/nutrients from agricultural operations
- Issue 2: Sediment/fecal coliform from livestock and wildlife
- Issue 3: Nutrients/chemicals from residential uses
- Issue 4: Sediment/nutrients from agricultural field ditches
- Issue 5: Nutrients/fecal coliform from improper functioning septic systems
- Issue 6: Sediment from gravel and summer roads
- Issue 7: Sediment from sheer or undercut banks
- Issue 8: Sediment/fecal coliform from stormwater
- Issue 9: Sediment from poor forestry management
- Issue 10: Sediment from roadside ditching
- Issue 11: Solar heating from lack of riparian shade

Other water quality issues were identified for the Hangman watershed during the public meetings and by the committee. The following issues were reviewed by the committee, but because they were not actual issues directly affecting the parameters of interest (fecal coliform, turbidity, temperature, and phosphorus), or they were outside the scope of what this effort could reasonably achieve, they were not included as issues to address through implementation activities for the TMDL.

Sediment from sandbanks in the lower part of the watershed
Chemicals from road deicer
Chemicals from agricultural chemical application
County enforcement of regulations
State enforcement of regulations
Development/Permits
New wetland construction and maintenance of existing wetlands
Maintain/increase existing healthy, functioning riparian areas
Return stream to original channel
Drain tile in agricultural fields
Rock pits/blasting
Increase instream flows
Invasive aquatic plants
Beaver ponds

The 11 issues identified by the Advisory Committee need to be addressed to bring the streams in the Hangman Creek Watershed into compliance with the water quality standards and reduce the phosphorus entering the Spokane River. The technical analysis earlier in this document helps prioritize where initial efforts should be focused by setting wasteload and load allocations for four parameters: 1) fecal coliform bacteria, 2) temperature, 3) total phosphorus and 4) turbidity/total suspended solids (TSS). Wasteload allocations were established for the six wastewater treatment facilities and the three entities covered under a stormwater permit. The wasteload allocations will ensure these facilities discharge pollutants at a level that is protective of water quality.

The load allocations to address nonpoint sources of the pollutants are set geographically by establishing the reductions needed at different points throughout the watershed and sub-watersheds. Most nonpoint sources are present throughout the watershed, although urban sources are more concentrated in the lower part of the watershed.

Possible point and nonpoint for each parameter this TMDL are indicated in Table X.

Table X. Possible Sources of Each Pollutant.

Possible Source	Fecal Coliform Bacteria	Temperature	Total Phosphorus	Turbidity/ Total Suspended Solids
Agricultural operations		x	x	x
Livestock	x	x	x	x
Wildlife	x		x	
Residential fertilizer use			x	
Agricultural field ditches			x	x
Malfunctioning septic systems	x		x	
Gravel and summer roads			x	x
Sheer and undercut stream banks			x	x
Stormwater	x		x	x
Roadside ditching			x	x
Wastewater treatment plants	x	x	x	x
Forestry management		x		x

The point sources (wastewater treatment plants and stormwater facilities) will be addressed through the issuance of their NPDES permits. These permits will reflect the wasteload allocations established earlier in this document and if necessary a compliance schedule to meet those allocations. More detail about the implementation of these wasteload allocations is discussed below under "Who Needs to Participate."

To address the nonpoint sources, the advisory committee developed a list of best management practices to address each of the nonpoint source water quality issues identified. Stormwater is included because much of the watershed is not covered under a stormwater permit. The advisory committee worked through each BMP identifying potential barriers and benefits to implementing each one (Appendix X). The purpose of this exercise was to lay the groundwork for the implementation plan. An understanding of the barriers agencies and organizations may encounter when trying to improve water quality should facilitate implementation. Likewise, understanding the benefits of the BMPs will help education and outreach efforts during implementation. Appendix X outlines the results of this exercise.

Many of the BMPs address more than one of the water quality issues. To address the water quality parameters addressed by this TMDL, pollution reductions will be accomplished through best management practices that:

- Reduce erosion.
- Reduce runoff carrying sediment.
- Reduce livestock impacts.
- Increase shading of streams.
- Inform and educate watershed residents about water quality issues.

Table X shows BMPs the advisory committee believed would help address each water quality issue.

Table X. Best Management Practices (BMPs) for water quality issues related to sources of pollutants covered by this TMDL.

Water Quality Issue	**Best Management Practices**						
Issue 1: Sediment/nutrients from agricultural operations	Direct Seed Tillage Operations (No Till/Minimum Till)	Riparian Buffers	Sediment Basins	Grassed Waterways	Filter Strips	Divided Slopes	
Issue 2: Sediment/fecal coliform from livestock and wildlife	Riparian Buffers	Livestock Fencing and off-stream watering	Manure Retention Facilities	Off-Stream Watering	Intensive Management Grazing	Nutrient and manure management	
Issue 3: Nutrients/chemicals from residential uses	Education about fertilizer management	Septic system maintenance, repair and replacement	Pet waste management	Proper use and disposal of household chemicals	Proper use and disposal of pesticides and fertilzers	Proper disposal of lawn clippings	Follow sho managemer regulations
Issue 4: Sediment/nutrients from agricultural field ditches	Uphill plowing	Ditch maintenance	Proper construction and engineering	Conversion to grassed waterways			
Issue 5: Nutrients/fecal coliform from improper functioning septic systems	Education on the negative affects of garbage disposals	Have system inspected every 1-3 years	Remove roof drains from system and away from the drainfield	Education about what should and should not go into septic systems	Comment on new developments through SEPA process	Repair or replace failing systems	
Issue 6: Sediment from gravel and summer roads	Pave roads	Close roads in winter	Increase grading and graveling				
Issue 7: Sediment from sheer or undercut banks	Plant vegetation	Reshape bands and plant vegetation	Install engineered structures				
Issue 8: Sediment/fecal coliform from stormwater	Road runoff to sediment basins	Implement practices in the Eastern Washington Stormwater Manual					
Issue 9: Sediment from poor forestry management	Selective harvest	Stream crossings need to follow requirements in WAC 222-24-040	Forested streamside management zones required for fish-bearing and perennial non-fish waters (WAC 222-30)	Limit equipment in streamside management zones for seasonal non-fish waters (WAC 222-30)	Proper road planning, construction and maintenance (follow WAC 222-24)		
Issue 10: Sediment from roadside ditching	Design and implement vegetated ditches	Install detention basins					
Issue 11: Solar heating from lack of riparian shade	Riparian restoration projects	Riparian buffers	Livestock fencing and off-stream watering				

Who needs to participate?

Implementation activities will generally involve the agencies responsible for the development of the implementation strategy; namely, the Spokane County Conservation District, Washington Department of Ecology, Spokane County, the City of Spokane, the 6 wastewater treatment plants, the Coeur d' Alene Tribe and the Environmental Protection Agency. Implementation will be jointly facilitated and tracked by the Spokane Conservation District and the Department of Ecology. These agencies will also involve other agencies and groups, such as the Spokane Regional Health District, the Direct Seed Association, Washington State University Extension, seed and fertilizer companies, local producer based cooperatives, the Natural Resources Conservation Service, and the Farm Service Agency.

Washington Department of Ecology

Ecology will work with the various agencies in the watershed to ensure progress is being made toward meeting the water quality standards for fecal coliform, temperature and turbidity and toward meeting the phosphorus allocations set by the Spokane River Dissolved Oxygen TMDL. Ecology, in cooperation with the Spokane County Conservation District will develop a Water Quality Implementation Plan (WQIP) which will detail the specific activities that will be done to facilitate meeting these goals.

Ecology will regulate stormwater discharges through the Construction, Municipal, Industrial, and the Washington State Department of Transportation (WSDOT) Stormwater Permits.

A ***Construction Stormwater Permit*** is required for all soil disturbing activities (including clearing, grading, and/or excavation) where one or more acre will be disturbed, and stormwater will be directly discharged to a receiving water (e.g., wetlands, creeks, unnamed creeks, rivers, marine waters, ditches, estuaries), or to storm drains that discharge to a receiving water. A permit is also required for construction projects smaller than one acre if the project is part of a "common plan of development or sale" in which the total land disturbance exceeds one acre. Any size construction activity may be required to obtain a permit if Ecology determines it to be a significant source of pollutants to waters of the state. If all stormwater is retained on-site and cannot enter surface waters of the state under any condition, permit coverage is not needed. Construction site operators must apply for a permit 60 days prior to discharging stormwater.

A ***Municipal Stormwater Permit*** is required for public entities in urbanized areas (as defined by the 2000 Census) that operate municipal separate storm sewer systems (MS4). The City of Spokane and Spokane County are included under the Phase II Municipal Stormwater Permit for Eastern Washington.

Coverage under the ***Industrial Stormwater General Permit*** is required for industrial facilities that discharge stormwater from their industrial areas to waters of the state, or to storm drains that discharge to waters of the state. No permit is required if the facility treats and retains all the stormwater on site. Currently there are no industrial facilities within the watershed required to have coverage under this permit.

The Washington State Department of Transportation is required to focus implementation of its stormwater management program (SWMP), including water quality monitoring and field investigations of illicit discharges into its conveyances. WSDOT shall report the findings of its investigations and the actions taken to implement its SWMP in the annual report

Ecology will include WLAs for all addressed parameters in the NPDES permits for Tekoa, Fairfield, Spangle, Rockford, Cheney, and the Freeman School District's WWTPs. These WLAs will ensure point sources are not causing the streams to violate water quality standards. The NPDES permits will include monitoring requirements and if necessary future permits will include a compliance schedule. Ecology recognizes the difficultly of meeting the temperature and phosphorus WLAs even with treatment plant improvements and will continue to work with the facilities to find solutions. Considering the temperature analysis indicates the streams could not meet the numeric criteria even under the best potential vegetation conditions, Ecology will consider evidence indicating whether or not the correct water quality criteria are being applied.

Ecology's Water Quality Program will also monitor the progress of the WQIP, review monitoring data, and apply adaptive management if implementation does not move the streams towards meeting water quality goals in a timely enough manner.

Spokane County Conservation District

The Spokane County Conservation District (SCCD), in cooperation with Ecology will develop a Water Quality Implementation Plan (WQIP) which will outline the specific activities that will be done to meet the goals of this TMDL. The SCCD will use existing and future funding sources to implement BMPs, activities and educational programs recommended in this report and the future WQIP. The SCCD will provide technical assistance to landowners who want to restore riparian areas, fence livestock from streams, implement direct seed tillage operations and other conservation activities.

Tekoa, Fairfield, Rockford, Spangle, Cheney and the Freeman School District's Wastewater Treatment Plants

The current wasteload allocations (WLAs) for fecal coliform and turbidity and solids in the NPDES permits for these facilities are adequate to protect water quality and will be continued in future permits. The recommended temperature and phosphorus wasteload allocations will be incorporated into their NPDES permits when they are re-issued. Improvements to each of the facilities may be necessary to meet the WLAs for temperature and phosphorus. The phosphorus and temperature discharge limits may be difficult wasteload allocations for these facilities to meet considering technological and financial limitations. The NPDES permits should contain compliance schedules that outline a reasonable schedule for meeting these targets.

Some options these facilities can consider to reduce their effluent temperature are discussed in "Methods to Reduce or Avoid Thermal Impacts to Surface Water" (Skillings Connolly, Inc, 2007). Samples of these options include:

- Clarifier covers.
- Seasonal storage.

- Land application.
- Infiltration trenches.
- Wastewater reclamation and reuse.
- Riparian shading.

Interim temperature effluent limits and compliance schedules will be developed using Ecology's "Water Quality Program Guidance – Implementing Washington State Temperature Standards through TMDLs and NPDES Permits" (Hicks, 2007).

A schedule for meeting the phosphorus WLAs will be developed with each facility. Because phosphorus is most likely to reach the Spokane River during periods of high flows, meeting wasteload allocations during the April-June season should be the first priority. A recommended schedule is provided in Table X below. In addition interim target effluent concentrations may be developed as part of the NPDES permits. To meet the phosphorus WLAs, several facilities may need to treat to a level that will require a Class III WWTP Operator. These facilities may consider forming a combined sewer district or public utility district to share a Class III WWTP Operator. The WWTP facilities could also investigate the possibility of removing their discharge from the stream by switching to land treatment either seasonally or year-round. These facilities should work closely with their Ecology permit manager to develop a compliance schedule to meet the wasteload allocations set in this TMDL. But the schedule shall not exceed 15 years. Cheney WWTP should continue to maintain a non-discharging wetland unless groundwater studies prove this to be ineffective treatment for phosphorus

Table X. Recommended schedule for meeting phosphorus WLAs

Meet 0.05mg/L effluent concentration during April-June	Meet 0.05mg/L effluent concentration during April-October	Meet 0.05mg/L effluent concentration year round
5 years	10 years	15 years

All facilities will need to initiate monitoring phosphorus concentrations and loads in their effluent. This data may be used to refine load and wasteload allocations in the future. In addition, future watershed studies may provide better insight into effluent phosphorus delivery to the Spokane River. Such studies may provide information that would allow the wasteload allocations to be adjusted seasonally.

City of Spokane, Spokane County and WSDOT

The activities recommended in this TMDL include controlling sediment (turbidity), phosphorus and fecal coliform from stormwater. Spokane County and the City of Spokane have been included under the Phase II Municipal Stormwater Permit. In addition, WSDOT highways within these Phase II areas are included under WSDOT's stormwater permit. These permits require the implementation of the following stormwater management elements:

- Public education and outreach
- Public involvement and participation
- Illicit discharge detection and elimination

- Construction site stormwater runoff control
- Post-construction stormwater management
- Pollution prevention and good housekeeping for municipal operations
- Requirements based on approved Total Maximum Daily Loads (TMDLs)
- Evaluations of program compliance

Many pollutants in stormwater can be controlled through best management practices. The Eastern Washington Stormwater Manual recommends various BMPs to address specific pollutants.

The stormwater permits for these entities will be re-issued in 2012. As a result of this TMDL, the following activities may be included in the revised permit:

- Inventory stormwater outfalls to determine which outfalls have the greatest impacts directly to waterbodies.
- Include fecal coliform, temperature, phosphorus, turbidity and total suspended solids in stormwater monitoring to better characterize pollutant loads coming from this source. If necessary, wasteload and load allocations may be adjusted based on an improved understanding of stormwater pollutant loads.
- All stormwater monitoring requires an approved Quality Assurance Project Plan.
- Capture storm events in the monitoring effort.
- Monitoring results will be compared to the WLAs established in this TMDL and if the results exceed the allocations, appropriate BMPs will be put into place to protect water quality.

To implement the regulations, Ecology uses a narrative Best Management Practice (BMP) approach to stormwater control rather than numeric effluent limitations. The Permit and the stormwater manual approach defines the level of effort required for each of the requirements as part of the permit development and issuance process. It bases requirements on recognized practices from existing programs, uses compliance schedules where appropriate, focuses efforts on development of local programs that protect existing water quality rather than restoring degraded areas (except where mandated by TMDLs), and requires each permit holder to evaluate the effectiveness of the entity's Stormwater Management Program (SWMP).

Department of Natural Resources and Forest Practitioners

The state's forest practices regulations will be relied upon to bring waters into compliance with the load allocations established in this TMDL on private and state forestlands. As part of the 1999 Forests and Fish agreement (www.dnr.wa.gov/forestpractices/rules/forestsandfish.pdf), Ecology agreed to use the forest practices regulations to implement TMDLs. The effectiveness of the Forests and Fish program is being assessed through a formal adaptive management program. The success of this TMDL will be assessed using monitoring data from streams in the watershed.

Ecology will formally review the effectiveness of the forest practices program in 2009. As part of this review, Ecology will determine if the state's forest practices program can be relied on to bring water quality into compliance with the state water quality standards. If the current program is not found to be adequate, Ecology will suggest any needed changes to the Forest Practices Board, or revise this TMDL implementation plan as necessary, to achieve compliance.

Washington State Department of Natural Resources (DNR) is encouraged to condition forest practices to prohibit any further reduction of stream shade and not waive or modify any shade requirements for timber harvesting activities on state and private lands.

New forest practices rules for roads also apply. These include new road construction standards, as well as new standards and a schedule for upgrading existing roads. Under the new rules, roads must provide for better control of road-related sediments, provide better streambank stability protection, and meet current best management practices. DNR is also responsible for oversight of these activities.

Coeur d'Alene Tribe and the Environmental Protection Agency (EPA)

The Coeur d'Alene tribe (CDA) has been granted "Treatment as a State" by the EPA. The CDA Tribe has their own water quality standards and is responsible for developing TMDLs for waterbodies not meeting these standards. Hangman Creek is impaired for bacteria, habitat alteration, nutrients and sediment from the Reservation boundary to the Idaho/Washington state line. Little Hangman Creek, a tributary to Hangman Creek, is impaired from its headwaters to the state line for nutrients.

The Tribe has actively participated in the development of Washington's TMDL by providing data and local knowledge. Ecology modeled the whole watershed based on the data provided by the Tribe. The technical analyses in this TMDL include targets set at the border which ensure compliance with Washington's water quality standards. The CDA Tribe will develop TMDLs for the reservation waterways based on meeting their own water quality standards and the targets set at the border.

The EPA will need to ensure the Tensed treatment plant and any new wastewater facilities that discharge to surface water have NPDES permits protective of Washington's water quality standards and this TMDL.

What is the schedule for achieving water quality standards?

The ability to meet specific interim targets and milestones will depend on the funds available, the personnel and resources available, and the producers in the watershed. Some pollutants will take longer to reach water quality standards than others. For example, it will take longer to reach the temperature standards because of the time it takes to grow plants and trees that will shade the streams. Both phosphorus and turbidity/TSS will require the establishment of functioning riparian areas and stream bank stabilization. A proposed schedule for achieving water quality standards for each pollutant is shown in Table X.

Table X. Schedules for achieving water quality standards.

Percentage of TMDL targets achieved	Number of Years after TMDL Water Quality Improvement Plan completion			
	Fecal Coliform	Temperature	Phosphorus*	Turbidity/TSS
25%	3	10	5	5
50%	5	15	7	7
75%	8	20	10	10
100%	10	25	15	15

* Currently the TMDL analysis indicates that the Spokane River phosphorus allocations are less than Hangman Creek's loading capacity. This schedule may need to be revised as more information about loading capacity and natural conditions is obtained.

These targets will require significant commitment from all stakeholders. With out watershed wide commitment the targets may not be met. If the Idaho portion of the watershed does not commit to the goals of this TMDL, progress on the Washington side could be delayed.

Reasonable assurances

When establishing a TMDL, reductions of a particular pollutant are allocated among the pollutant sources (both point and nonpoint sources) in the waterbody. In the Hangman Creek watershed both point and nonpoint sources exist for fecal coliform, temperature, sediment/turbidity, and phosphorus. TMDLs (and related Action Plans) must show "reasonable assurance" that these sources will be reduced to their allocated amount. Education, outreach, technical and financial assistance, permit administration, and enforcement will all be used to ensure that the goals of this water improvement plan are met.

There is considerable interest and local involvement toward resolving the water quality problems in the Hangman Creek watershed. Numerous organizations and agencies are already engaged in stream restoration and source correction actions that will help resolve the fecal coliform, temperature, sediment/turbidity, and phosphorus problems.

Ecology and the Spokane County Conservation District believe that the following activities are already supporting this TMDL and add to the assurance that fecal coliform, temperature, sediment/turbidity, and phosphorus in Hangman Creek will meet conditions provided by Washington State water quality standards. This assumes that the activities described below are continued and maintained.

Ongoing-Efforts

Several local agencies have ongoing efforts that increase awareness on water quality issues in the watershed. Ecology, the Conservation Districts, Spokane and Whitman Counties, and the county Health Departments all have pamphlets, mailers, workshops and outreach programs on water quality education. Technical assistance is provided by NRCS, the Conservation Districts, and the Department of Ecology. The following are some of the current programs in the Hangman watershed that provided some type of nonpoint pollution control or environmental education.

Hangman Creek Watershed Planning (WRIA 56)

The 1998 legislature passed ESHB 2514, codified into Ch. 90.82 RCW, to set a framework for developing local solutions to watershed issues on a watershed basis. Watershed Planning Groups must plan for future water quantity needs but they can also choose to plan for water quality needs. The Hangman Creek Watershed Planning Unit formed in 1999 and opted to include water quality issues in their watershed plan. The Planning Unit completed their watershed plan in 2006 which includes many recommendations to improve water quality including participation in activities recommended in the TMDL. The planning unit is nearing completion of a Detailed Implementation Plan which outlines how and when various activities will be completed. This project has an education component, recommendations for increasing stream flows, and several recommendations for improved water quality.

Spokane River Dissolved Oxygen TMDL

The Spokane River Dissolved Oxygen TMDL relies partially on the reduction of phosphorus coming from Hangman Creek. Therefore, Spokane River discharges have interest in implementing BMPs and other phosphorus controlling methods in the Hangman Creek to help offset portions of their TP phosphorus allocations. Ecology and SCCD anticipate that many cooperative partnerships will be formed between entities involved in both TMDLs.

Spokane County Volunteer Water Quality Monitoring Project

The program is currently using volunteers to monitor water quality in the Hangman watershed at select locations. This program was started with an Ecology grant, but is currently being funded by the Spokane County Conservation District.

Spokane County Shorelines Inventory and Assessment Project (Ecology Grant)

This project by the Spokane County Conservation District evaluated and inventoried the riparian areas along Hangman, Rock, and California creeks. This provided a ranking system to target funding and technical assistance to areas of high priority for water quality restoration. This information will help prioritize future implementation activities.

Regulatory and Technical Assistance Programs

The following describes existing regulatory and technical assistance programs that provide reasonable assurance that the goals of this TMDL will be met.

Washington Department of Ecology

Ecology has authority under the federal Clean Water Act by the U.S. EPA to establish water quality standards, administer the NPDES wastewater permitting program, and enforce water quality regulations under Chapter 90.48 RCW. Ecology responds to complaints, conducts inspections, and issues NPDES permits as part of its responsibilities under state and federal laws and regulations. In cooperation with conservation districts, Ecology will pursue implementation of BMPs for agricultural and other land uses and may use formal enforcement, including fines, if voluntary compliance is unsuccessful.

Spokane County Conservation District and Pine Conservation District

The conservation districts have authority under Chapter 89.08 RCW to develop farm plans, protect water quality, and to provide animal waste management information, education and technical assistance to residents on a voluntary basis. Farmers receiving a Notice of Correction from Ecology or local health jurisdictions will normally be referred to the local conservation district for assistance. When developing farm plans, the districts use guidance and specifications from the U.S. Natural Resources Conservation Service.

In addition, the conservation districts seek and receive grant funds that will assist landowners to implement BMPs that improve riparian health and protect water quality to Hangman Creek and its associated tributaries.

Natural Resources Conservation Service (NRCS)
NRCS works closely with conservation districts to implement farm plans and agricultural BMP programs. NRCS is one of the primary entities for technical assistance and financial support to assist in the implementation of agricultural and livestock BMPs throughout the watershed.

Spokane and Whitman County Health Departments
The health departments regulate on-site sewage systems in the watershed in accordance with Chapter 246-272 WAC. When the department receives a complaint about a failing system, the department verifies the failure and assists the landowner with coming into compliance with Chapter 246-272 WAC. In addition, the health departments are often involved in the investigation of complaints about agricultural animal waste.

Spokane County, Whitman County, and City of Spokane
Hangman Creek falls under the requirements of the Shoreline Management Act (SMA) (RCW 90.58). The SMA is administered principally by local governments through locally developed Shoreline Master Programs (SMPs) and Ecology provides technical and financial assistance for the development and implementation of the SMPs.

Ecology reviews and approves the SMPs, and with local governments, has the authority for compliance and enforcement of the SMA and SMPs. Local governments review projects in their jurisdiction for compliance with local SMPs and the SMA, through a permit process. The SMA specifically lists protecting water quality as a purpose of the SMA (RCW 90.58.020). Local governments must periodically update their SMPs and must integrate them with their Growth Management Act provisions, including critical area ordinances. Spokane County began updating their SMP in 2003 and anticipates its completion by March of 2008.

State of Idaho, Coeur d'Alene Tribe, Environmental Protection Agency (EPA)
Since Hangman Creek, Little Hangman Creek and Rock Creek originate in Idaho, the work underway in Idaho and on the Coeur d'Alene Reservation has the potential to positively affect water quality in the Washington portion of the watershed. In Idaho, the water quality standards program is a joint effort between the Department of Environmental Quality (DEQ) and the EPA. DEQ is responsible for developing and enforcing water quality standards that protect beneficial uses such as drinking water, coldwater fisheries, industrial water supply, recreation, and

agricultural water supply. Likewise, the Coeur d'Alene Tribe has its own water quality standards and programs for the protection of surface water. The DEQ and Tribe have the authority and the responsibility to ensure that TMDLs are completed and submitted to EPA. The EPA develops regulations, policies, and guidance to help DEQ and the Tribe implement their programs and to ensure that their water quality standards and TMDLs are consistent with the requirements of the Clean Water Act and relevant regulations. The EPA has authority to review and approve (or disapprove) state standards and, where necessary, to promulgate federal water quality rules. TMDLs are being developed on the Coeur d'Alene Tribal Reservation and have been completed on stream segments under Idaho DEQ's jurisdiction.

Adaptive management

TMDL reductions should be achieved within 15 years of TMDL adoption. The *Water Quality Implementation Plan* will identify interim targets. These targets will be described in terms of concentrations and/or loads, as well as in terms of implemented cleanup actions. Partners will work together to monitor progress towards these goals, evaluate successes, obstacles, and changing needs, and make adjustments to the cleanup strategy as needed.

It is ultimately Ecology's responsibility to assure that cleanup is being actively pursued and water standards are achieved. See the *Monitoring Progress* section in this report. Adaptive management methods that may be used during implementation of this TMDL include:

- Adjusting best management practices
- Modifying stream sampling frequency and/or locations
- Developing and funding water quality projects that address pollution loads
- Local educational initiatives
- Assessing local watershed needs

Monitoring progress

A TMDL must include monitoring to measure achievement of targets and water quality standards. Monitoring also provides evidence that BMPs are having the desired results.

A quality assurance project plan (QAPP) should be prepared for all monitoring conducted. The QAPP should follow Ecology guidelines (Lombard and Kirchmer, 2004) paying particular attention to consistency in sampling and analytical methods.

The purpose of effectiveness monitoring is to discover if management activities and BMPs are improving water quality. Effectiveness monitoring results are used to determine if the interim targets and/or water quality standards are being achieved. Ecology usually performs this monitoring five years after the Water Quality Implementation Plan is finished. The ability for Ecology to conduct the monitoring in five years depends upon the availability of resources. If the streams are found to not meet the interim targets and/or water quality criteria, an adaptive management strategy will be adopted and future effectiveness monitoring will need to be scheduled.

The NPDES permits issued for the point sources in the watershed will require regular monitoring of fecal coliform, temperature, turbidity/total suspended solids and phosphorus levels in the treatment plant's effluent to ensure the facilities are in compliance with the permit limits or compliance schedule.

As BMP projects are put into place, monitoring on a project specific basis will be done as required by the granting or funding agency. Monitoring for watershed improvements will be scheduled at five-year intervals, depending on funding availability. The monitoring plan will be changed if necessary as an element of the adaptive management.

Entities with enforcement authority are responsible for following up on any enforcement actions. Stormwater permittees are responsible for meeting the requirements of their permits. Those conducting restoration projects or installing best management practices (BMPs) are responsible for monitoring plant survival rates and maintenance of improvements, structures and fencing.

During the next phase of this TMDL effort Ecology and the SCCD will develop a The *Water Quality Implementation Plan* (WQIP) which will outline a monitoring strategy which includes the monitoring recommendations made in the TMDL Analyses section of this report. Ecology and the SCCD will monitor the progress made towards implementing the actions outlined in this TMDL and the WQIP.

Potential funding sources

Ecology's Centennial Clean Water Fund, Section 319, and State Revolving Fund loans can provide funding resources to help implementation of the TMDL (water quality improvement plan). In addition to Ecology's funding programs, there are many other funding sources available for watershed planning and implementation, point and nonpoint source pollution management, fish and wildlife habitat enhancement, stream restoration, and education. Public sources of funding include federal and state government programs, which can offer financial as well as technical assistance. Private sources of funding include private foundations, which most often fund nonprofit organizations with tax-exempt status. Forming partnerships with other government agencies, nonprofit organizations, and private businesses can often be the most effective approach to maximize funding opportunities. Some of the most commonly accessed funding sources for TMDL implementation efforts are shown in Table x and are described below.

Table X. Potential Funding Sources for Implementation Projects.

Fund Source	Type of Project Funded	Maximum Amounts
Centennial Clean Water Fund	Watershed planning, stream restoration, & water pollution control projects.	$500,000
Section 319 Nonpoint Source Fund	Nonpoint source control; i.e., pet waste, stormwater runoff, & agriculture, etc.	$500,000
State Water Pollution Control Revolving Fund	Low-interest loans to upgrade pollution control facilities to address nonpoint source problems; failing septic systems.	10% of total SRF annually
Coastal Zone Protection Fund (also referred to as Terry Husseman grants)	Stream restoration projects to improve water quality.	~$50,000
Conservation Reserve Program (CRP)	Establishes long-term conservation cover of grasses, trees and shrubs on eligible land.	Rental payments based on the value of the land; plus 50% - 90% cost share dependant on practices implemented
Environmental Quality Incentives Program (EQIP)	Natural resource protection.	Dependent on practices implemented
Wildlife Habitat Incentive Program (WHIP)	Provide funds to enhance and protect wildlife habitat including water.	$25,000 dependent on practices implemented
Conservation Security Program (CSP)	Provides financial assistance for conservation on private working lands	Dependent on practices implemented
Housing Rehabilitation Loan Program	Loans to low-income homeowners for safety & sanitation.	0-6% interest dependent on household income
Wetland Reserve Program (WRP)	Wetland enhancement, restoration, and protection by retiring agricultural land.	Dependent on appraised land value

Centennial Clean Water Fund (CCWF)
A 1986 state statute created the Water Quality Account, which includes the Centennial Clean Water Fund (CCWF). Ecology offers CCWF grants and loans to local governments, tribes, and other public entities for water pollution control projects. The application process is the same for CCWF, 319 Nonpoint Source Fund, and the state Water Pollution Control Revolving Fund.

Section 319 Nonpoint Source Fund
The 319 Fund provides grants to local governments, tribes, state agencies and nonprofit organizations to address nonpoint source pollution to improve and protect water quality.

Nonpoint source pollution includes many diffuse sources of pollution, such as stormwater runoff from urban development, agricultural and timber practices, failing septic systems, pet waste, gardening, and other activities. Non-governmental organizations can apply to Ecology for funding through a 319 grant to provide additional implementation assistance.

State Water Pollution Control Revolving Fund

Ecology also administers the Washington State Water Pollution Control Revolving Fund. This program uses federal funding from U.S. Environmental Protection Agency and monies appropriated from the state's Water Quality Account to provide low-interest loans to local governments, tribes, and other public entities. The loans are primarily for upgrading or expanding water pollution control facilities, such as public sewage and stormwater plants, and for activities to address nonpoint source water quality problems.

Coastal Zone Protection Fund

Since July 1998, water quality penalties issued under Chapter 90.48 RCW have been deposited into a sub-account of the Coastal Protection Fund (also referred to as Terry Husseman grants). A portion of this fund is made available to regional Ecology offices to support on-the-ground projects to perform environmental restoration and enhancement. Local governments, tribes, and state agencies must propose projects through Ecology staff. Stakeholders with projects that will reduce bacterial pollution are encouraged to contact their local TMDL coordinator to determine if their project proposal is a good candidate for Coastal Zone Protection funding.

Conservation Reserve Program (CRP)

The Conservation Reserve Program (CRP) is a voluntary program for agricultural landowners. Through CRP, landowners can receive annual rental payments and cost-share assistance to establish long-term, resource conserving covers on eligible farmland. Included under CRP is the Continuous Conservation Reserve Program (CCRP), which provides funds for special practices for both upland and riparian land. Landowners can enroll in CCRP at anytime. There are designated sign up periods for CCRP.

The Commodity Credit Corporation (CCC) makes annual rental payments based on the agriculture rental value of the land, and it provides cost-share assistance for 50 to 90 percent of the participant's costs in establishing approved conservation practices. Participants enroll in CRP contracts for 10 to 15 years.

The program is administered by the CCC through the Farm Service Agency (FSA), and program support is provided by Natural Resources Conservation Service, Cooperative State Research and Education Extension Service, state forestry agencies, and local Soil and Water Conservation Districts. (Farm Service Agency, 2006)

Environmental Quality Incentives Program (EQIP)

The federally funded Environmental Quality Incentives Program (EQIP) is administered by NRCS. EQIP is the combination of several conservation programs that address soil, water, and related natural resource concerns. EQIP encourages environmental enhancements on land in an environmentally beneficial and cost-effective manner. The EQIP program:

- Provides technical assistance, cost share, and incentive payments to assist crop and livestock producers with environmental and conservation improvements on the farm.
- Has 75 percent cost sharing but allows 90 percent if producer is a limited resource or beginning farmer.
- Divides program funding 60 percent for livestock-related practices, 40 percent for cropland.
- Has contracts lasting five to ten years.
- Has no annual payment limitation; sum not to exceed $450,000 per farm.

Wildlife Habitat Incentive Program
The Wildlife Habitat Incentive Program (WHIP) is administered by NRCS. WHIP is a voluntary program for people who want to develop and improve wildlife habitat primarily on private land. Through WHIP, NRCS provides both technical assistance and up to 75 percent cost-share assistance to establish and improve fish and wildlife habitat. WHIP agreements between NRCS and the participant generally last from five to ten years from the date the agreement is signed.

Conservation Security Program
The Conservation Security Program (CSP) is a voluntary program that provides financial and technical assistance to promote the conservation and improvement of soil, water, air, energy, plant and animal life, and other conservation purposes on tribal and private working lands. Working lands include cropland, grassland, prairie land, improved pasture, and range land, as well as forested land that is an incidental part of an agriculture operation. The program provides equitable access to benefits to all producers, regardless of size of operation, crops produced, or geographic location. CSP is administered by NRCS (NRCS, 2006).

Each year different watersheds are selected for CSP enrollment. It is not known when this program will come to the North Fork Palouse watershed. However, since the program rewards producers who already have conservation practices in place, producers are encouraged to use other federal, state, and local funding sources to prepare their land for enrollment (R. Riehle, NRCS 2006, per comm. March 17).

Housing Rehabilitation Loan Program
The Housing Rehabilitation Loan Program provides zero-interest and low-interest loans to residents to repair and improve the quality and safety of their homes. These loans can be used to repair and replace failing septic systems. Interest rates are based on household income. To qualify for this funding, homeowners must have an inspection performed for there residence and upgrade any other potential health risks that are identified.

Rural Housing Repair and Rehabilitation Loans
The Rural Housing Repair and Rehabilitation Loans are funded directly by the federal government. Loans are available to low-income rural residents who own and occupy a dwelling in need of repairs. Funds are available for repairs to improve or modernize a home, or to remove health and safety hazards such as a failing on-site system. This loan is a one percent loan that may be repaid over a 20-year period.

To obtain a loan, homeowner-occupants must have low income (defined as under 50 percent of the area median income), and be unable to obtain affordable credit elsewhere. They must need to make repairs and improvements to make the dwelling more safe and sanitary. Grants (up to $7,500) are available only to homeowners who are 62 years old or older and who cannot repay a Section 504 loan (USDA, 2006).

Wetland Reserve Program (WRP)
The Wetland Reserve Program (WRP) is a voluntary program administered by NRCS to restore and protect wetlands on private property (including farmland that has become a wetland as a result of flooding). The WRP provides technical and financial assistance to eligible landowners to address wetland, wildlife habitat, soil, water, and related natural resource concerns on private lands. The program offers three enrollment options: permanent easement, 30-year easement, and restoration cost-share agreement. Landowners receive financial incentives to enhance wetlands in exchange for retiring marginal agricultural land.

Under WRP, the landowner limits future use of the land, but retains ownership, controls access, and may lease the land for undeveloped recreational activities and possibly other compatible uses. Compatible uses are allowed if they are fully consistent with the protection and enhancement of the wetland.

Implementation Grant (Conservation Commission Grant)
The Spokane County Conservation District has an implementation grant from the Conservation Commission to provide cost-share funding for all farm plan approved BMPs.

County-Wide Riparian Cost-Share Buffer Program (Ecology Grant)
The Spokane County Conservation District has a cost-share program to help landowners to improve riparian areas, fence out livestock and provide off-creek watering, and revegetate stream sides.

Spokane River TMDL
The Managed Implementation Plan for the Spokane River Dissolved Oxygen includes funding BMPs and other nonpoint source controls in the tributary watersheds.

Spokane County Conservation District SRF Program (Ecology Grant)
This funding program provides low interest loans to producers in the watershed for purchase of conservation equipment, such as direct seed drills. Increasing direct seed in the watershed will help reduce polluted runoff and erosion.

Summary of public involvement methods

The Hangman TMDL work group was formed after two public meetings held in the watershed on March 24th and 25th 2004. Announcements were posted throughout the watershed, and 238 postcard announcements were sent to local businesses, towns, and residences that have indicated they were interested in Hangman water quality. The first public meeting was held in Fairfield, in the upper part of the watershed that is representative of agricultural and livestock landuses. The second public meeting was held in Marshall, in the lower part of the watershed and better represented the small acreage and urban landuses. From the list of interested persons generated at the two public meetings, an organizational meeting was held in Fairfield on April 29th, 2004. Workgroup meetings have been monthly, with the exception of some months that were skipped during harvest and/or for holidays or waiting for the completion of the load analysis.

Several agencies and landuses were represented at the meetings:

- Ecology
- City of Spokane
- Spokane County
- Coeur d' Alene Tribe
- Agricultural operators
- Timber operators
- Livestock operators
- Small acreage landowners
- Local community representatives

The local citizens and agency personnel have worked collaboratively to identify the water quality issues throughout the watershed and to propose workable Best Management Practices (BMPs) and other solutions. Several of the activities to address these water quality issues not only cover the fecal coliform bacteria, turbidity, temperature and nutrients targeted by this TMDL and the Spokane River TMDL, but also are intended to reduce other nutrients and raise the dissolved oxygen.

The advisory committee has provided information on the TMDL and water cleanup plan being discussed at several local events. These include:

a. Presented summary of small acreage BMS and review of SIS to local landowner meeting. This meeting had approximately 12 local landowners in attendance.
b. Presented summary of agricultural BMPs and review of SIS to local producer meeting. This meeting had over 250 local grower and producers in attendance.
c. Presented summary of livestock BMPs and issues to local watershed livestock owners. Approximately 35 persons attended the meeting.
d. Presented a display at the Southeast County fair in Rockford Washington.
e. Setup TMDL information booth at Fairfield Flag Day celebration and Tekoa Slippery Gulch Days.
f. Annually attended local city/town council meetings and gave brief presentation of TMDL project.
g. Presented a display at the Country Living Expo and the Ag Expo.
h. Provide articles for local Conservation District news letter.

A 30-day public comment period was held from __________ to __________2008. A press release announced the comment period and display ads were placed in _________________, ____________ and _____________ newspapers. Comments received are responded to in Appendix X.

Throughout the project development information has been available on the internet at http://www.ecy.wa.gov/programs/wq/tmdl/hangman_cr/index.html.

Next steps

Once EPA approves the TMDL, a *Water Quality Implementation Plan* (WQIP) must be developed within one year. Ecology and the SCCE will work with local people to create this plan, choosing the combination of possible solutions they think will be most effective in their watershed. Elements of this plan include:

- Who will commit to do what.
- How to determine if the implementation plan works.
- What to do if the implementation plan doesn't work.
- Potential funding sources.

In developing the WQIP, Ecology and the SCCD will ensure the plan addresses the recommendations made in the TMDL Analyses section of this report.

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Appendices

Appendix A. Glossary and Acronyms

303(d) list: Section 303(d) of the federal Clean Water Act requires Washington State periodically to prepare a list of all surface waters in the state for which beneficial uses of the water – such as for drinking, recreation, aquatic habitat, and industrial use – are impaired by pollutants. These are water quality limited estuaries, lakes, and streams that fall short of state surface water quality standards, and are not expected to improve within the next two years.

Ambient: Surrounding, encompassing, or natural conditions or environment.

Anadromous: Types of fish, such as salmon, that go from the sea to freshwater to spawn.

Antidegradation: Cannot degrade the stream or system any further than what it is presently.

Benthic: Assemblage of plants and animals living on the sea or stream bottom.

Best management practices (BMPs): Physical, structural, and/or operational practices that, when used singularly or in combination, prevent or reduce pollutant discharges.

Biological oxygen demand (BOD): The amount of oxygen concentration consumed by organic/biological organisms.

CAFO: Confined Animal Feeding Operation.

Clean Water Act (CWA): Federal Act passed in 1972 that contains provisions to restore and maintain the quality of the nation's waters. Section 303(d) of the CWA establishes the TMDL program.

Concentration: The amount or mass of a substance or material in a given volume or mass of sample. Concentrations of fecal coliform bacteria are usually measured in colony forming units per 100 milliliters of water (Cfu/100 ml). Other parameters are usually measured in milligrams per liter (mg/l), or parts per million (ppm), which are approximately equivalent at low concentration waters.

Cubic feet per second (CFS): Measure of water passing a point, the number of cubic feet that pass through a stream cross-section each second.

Designated uses: Those uses specified in Chapter 173-201A WAC (Water Quality Standards for Surface Waters of the State of Washington) for each waterbody or segment, regardless of whether or not the uses are currently attained.

DO: Dissolved oxygen, a measure of the amount of oxygen dissolved in the water and available for aquatic organisms use.

Effective shade: The fraction of incoming solar shortwave radiation that is blocked from reaching the surface of a stream or other defined area.

Enterococci: A subgroup of the fecal streptococci that includes S. *faecalis, S. faecium , S. gallinarum* and *S. avium*. The enterococci are differentiated from other streptococci by their ability to grow in 6.5% sodium chloride, at pH 9.6, and at 10 degrees C and 45 degrees C.

Eutrophication: Enrichment of a lake's plant growth by an influx of excess nutrients required for the plant growth.

Existing uses: Those uses actually attained in fresh and marine waters on or after November 28, 1975, whether or not they are designated uses. Introduced species that are not native to Washington, and put-and-take fisheries comprised of nonself-replicating introduced native species, do not need to receive full support as an existing use.

Extraordinary primary contact: Waters providing extraordinary protection against waterborne disease or that serve as tributaries to extraordinary quality shellfish harvesting areas.

Fecal coliform (FC): That portion of the coliform group of bacteria which is present in intestinal tracts and feces of warm-blooded animals as detected by the product of acid or gas from lactose in a suitable culture medium within twenty-four hours at 44.5 plus or minus 0.2 degrees Celsius. FC are "indicator" organisms that suggest the possible presence of disease-causing organisms. Concentrations are measured in colony forming units per 100 milliliters of water (cfu/100mL).

Geometric mean: A mathematical expression of the central tendency (an average) of multiple sample values. A geometric mean, unlike an arithmetic mean, tends to dampen the effect of very high or low values, which might bias the mean if a straight average (arithmetic mean) were calculated. This is helpful when analyzing bacteria concentrations, because levels may vary anywhere from ten to 10,000 fold over a given period. The calculation is performed by: 1) taking the nth root of a product of n factors, or 2) taking the antilogarithm of the arithmetic mean of the logarithms of the individual values.

LSR: Little Spokane River.

Load allocation (LA): The portion of a receiving waters' loading capacity attributed to one or more of its existing or future sources of nonpoint pollution or to natural background sources.

Loading capacity: The greatest amount of a substance that a waterbody can receive and still meet water quality standards.

Lognormal distribution:

Margin of safety (MOS): Required component of TMDLs that accounts for uncertainty about the relationship between pollutant loads and quality of the receiving waterbody.

mg/l: Milligrams per liter, approximately equal to parts per million in low concentration waters.

National Pollutant Discharge Elimination System (NPDES): National program for issuing, modifying, revoking and reissuing, terminating, monitoring and enforcing permits, and imposing and enforcing pretreatment requirements under the Clean Water Act. The NPDES program regulates discharges from wastewater treatment plants, large factories, and other facilities that use, process, and discharge water back into lakes, streams, rivers, bays, and oceans.

Nonpoint source: Pollution that enters any waters of the state from any dispersed land-based or water-based activities, including but not limited to atmospheric deposition, surface water runoff from agricultural lands, urban areas, or forest lands, subsurface or underground sources, or discharges from boats or marine vessels not otherwise regulated under the National Pollutant Discharge Elimination System Program. Generally, any unconfined and diffuse source of contamination. Legally, any source of water pollution that does not meet the legal definition of "point source" in section 502(14) of the Clean Water Act.

Ninetieth percentile (90th percentile): An estimated portion of a sample population based on a statistical determination of distribution characteristics. The 90th percentile value is a statistically derived estimate of the division between 90 percent of samples, which should be less than the value, and 10 percent of samples, which are expected to exceed the value.

Pathogen: Disease-causing microorganisms such as bacteria, protozoa, viruses.

pH: A measure of the acidity of a water, the negative log of the hydrogen ion concentration.

Point Source: Sources of pollution that discharge at a specific location from pipes, outfalls, and conveyance channels to a surface water. Examples of point source discharges include municipal wastewater treatment plants, municipal stormwater systems, industrial waste treatment facilities, and construction sites that clear more than 5 acres of land.

Pollution: Such contamination, or other alteration of the physical, chemical, or biological properties, of any waters of the state, including change in temperature, taste, color, turbidity, or odor of the waters, or such discharge of any liquid, gaseous, solid, radioactive, or other substance into any waters of the state as will or is likely to create a nuisance or render such waters harmful, detrimental, or injurious to the public health, safety, or welfare, or to domestic, commercial, industrial, agricultural, recreational, or other legitimate beneficial uses, or to livestock, wild animals, birds, fish, or other aquatic life.

Primary contact recreation: Activities where a person would have direct contact with water to the point of complete submergence including, but not limited to, skin diving, swimming, and water skiing.

QAPP: Quality Assurance Project Plan, a document required by Ecology for water quality sampling.

Riparian: Transitional zone between aquatic and upland areas. The area has vegetation or other physical features reflecting permanent influence of surface or subsurface water.

River mile (RM): A measure of river or stream length starting at the mouth of the river or stream.

Salmonid: Belonging to the family Salmonidae, which includes salmon, trout and whitefishes.

Statistical rollback method: The statistical rollback method is an approach to working up environmental data that predicts pollutant concentrations after pollutant controls have been implemented.

Stormwater: The portion of precipitation that does not naturally percolate into the ground or evaporate but instead runs off roads, pavement, and roofs during rainfall or snow melt. Stormwater can also come from hard or saturated grass surfaces such as lawns, pastures, playfields, and from gravel roads and parking lots.

Surface waters of the state: Lakes, rivers, ponds, streams, inland waters, saltwaters, wetlands and all other surface waters and water courses within the jurisdiction of Washington State.

Total Maximum Daily Load (TMDL): A distribution of a substance in a waterbody designed to protect it from exceeding water quality standards. A TMDL is equal to the sum of all of the following: (1) individual wasteload allocations (WLAs) for point sources, (2) the load allocations (LAs) for nonpoint sources, (3) the contribution of natural sources, and (4) a Margin of Safety to allow for uncertainty in the wasteload determination. A reserve for future growth is also generally provided.

Wasteload allocation (WLA): The portion of a receiving water's loading capacity allocated to existing or future point sources of pollution. WLAs constitute one type of water quality-based effluent limitation.

Watershed: A drainage area or basin in which all land and water areas drain or flow toward a central collector such as a stream, river, or lake at a lower elevation.

WRIA: Water Resource Inventory Area.

WRIA 56: Hangman Creek Water Resource Inventory Area.

Appendix x. (title)

Overview of Stream Heating Processes

The temperature of a stream reflects the amount of heat energy in the water. Changes in water temperature within a particular segment of a stream are induced by the balance of the heat exchange between the water and the surrounding environment during transport through the segment. If there is more heat energy entering the water in a stream segment than there is leaving, the temperature will increase. If there is less heat energy entering the water in a stream segment than there is leaving, then the temperature will decrease. The general relationships between stream parameters, thermodynamic processes (heat and mass transfer) and stream temperature change is outlined in Figure 1.

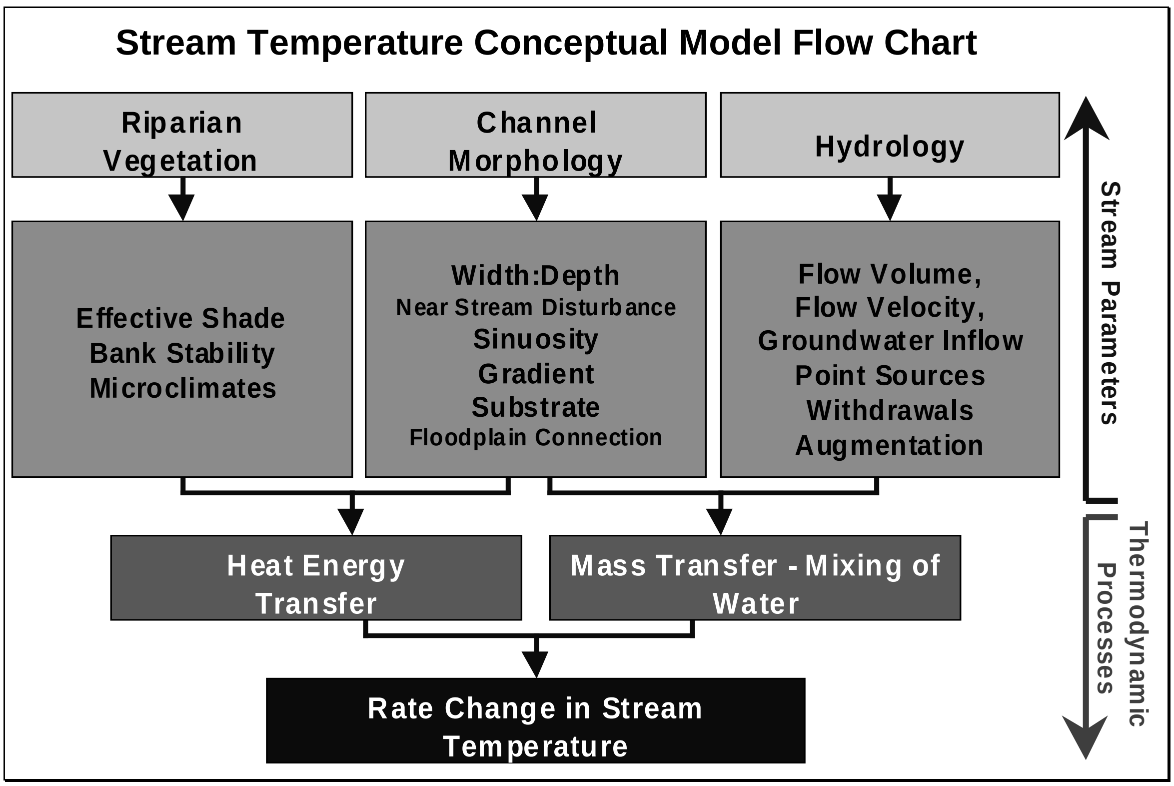

Figure X1. Conceptual model of factors that affect stream temperature.

Adams and Sullivan (1989) reported that the following environmental variables were the most important drivers of water temperature in forested streams:

- *Stream depth.* Stream depth affects both the magnitude of the stream temperature fluctuations and the response time of the stream to changes in environmental conditions.
- *Air temperature.* Daily average stream temperatures and daily average air temperatures are both highly influenced by incoming solar radiation (Johnson, 2004). When the sun is not shining, the water temperature in a volume of water tends toward the dew-point temperature (Edinger et al., 1974).
- *Solar radiation and riparian vegetation.* The daily maximum temperatures in a stream are strongly influenced by removal of riparian vegetation because of diurnal patterns of solar heat flux. Daily average temperatures are less affected by removal of riparian vegetation.
- *Groundwater.* Inflows of groundwater can have an important cooling effect on stream temperature. This effect will depend on the rate of groundwater inflow relative the flow in the stream and the difference in temperatures between the groundwater and the stream.

Heat budgets and temperature prediction

Heat exchange processes occur between the water body and the surrounding environment and control stream temperature. Edinger et al. (1974) and Chapra (1997) provide thorough descriptions of the physical processes involved. Figure 2 shows the major heat energy processes or fluxes across the water surface or streambed.

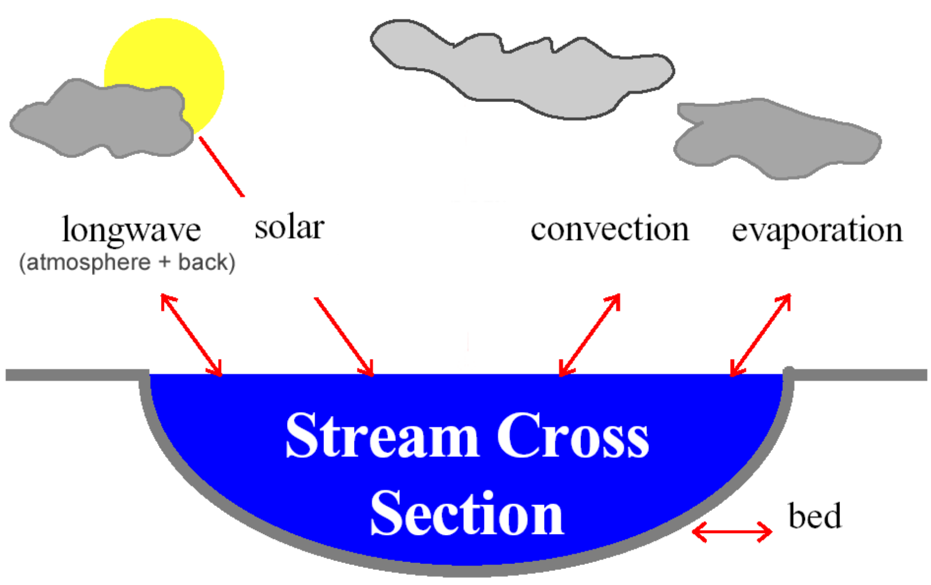

Figure X2. Surface heat exchange processes that affect water temperature (net heat flux = solar + longwave atmosphere + longwave back + convection + evaporation + bed). Heat flux between the water and streambed occurs through conduction and hyporheic exchange.

The heat exchange processes with the greatest magnitude are as follows (Edinger et al., 1974):

- **Short-wave solar radiation**. Short-wave solar radiation is the radiant energy which passes directly from the sun to the earth. Short-wave solar radiation is contained in a wavelength range between 0.14 μm and about 4 μm. At Washington State University's (WSU) TreeForest Research and Extension Center (TFREC) station in Wenatchee, the daily average global shortwave solar radiation for August 2002 was 259 W/m2. The peak values during daylight hours are typically about 3 times higher than the daily average. Short-wave solar radiation constitutes the major thermal input to an un-shaded body of water during the day when the sky is clear.
- **Long-wave atmospheric radiation.** The long-wave radiation from the atmosphere ranges in wavelength range from about 4 μm to 120 μm. Long-wave atmospheric radiation depends primarily on air temperature and humidity and increases as both of those increase. It constitutes the major thermal input to a body of water at night and on warm cloudy days. The daily average heat flux from long-wave atmospheric radiation typically ranges from about 300 to 450 W/m^2 at mid latitudes (Edinger et al., 1974).
- **Long-wave back radiation from the water to the atmosphere.** Water sends heat energy back to the atmosphere in the form of long-wave radiation in the wavelength range from about 4 μm to 120 μm. Back radiation accounts for a major portion of the heat loss from a body of water. Back radiation increases as water temperature increases. The daily average heat flux out of the water from long-wave back radiation typically ranges from about 300 to 500 W/m^2 (Edinger et al., 1974).

The remaining heat exchange processes generally have less magnitude and are as follows:

- **Evaporation flux at the air-water interface** is influenced mostly by the wind speed and the vapor pressure gradient between the water surface and the air. When the air is saturated, the evaporation stops. When the gradient is negative (vapor pressure at the water surface is less than the vapor pressure of the air), condensation, the reversal of evaporation takes place, and this term then becomes a gain component in the heat balance.
- **Convection flux at the air-water interface** is driven by the temperature difference between water and air and by the wind speed. Heat is transferred in the direction of decreasing temperature
- **Bed conduction flux and hyporheic exchange** component of the heat budget represents the heat exchange through conduction between the bed and the water body and the influence of hyporheic exchange. The magnitude of bed conduction is driven by the size and conductance properties of the substrate. The heat transfer through conduction is more pronounced when thermal differences between the substrate and water column are higher and usually affects the temperature diel profile, rather than affecting the magnitude of the maximum daily water temperature. Hyporheic exchange recently received increased attention as a possible important mechanism for stream cooling (Johnson and Jones, 2000, Poole and Berman, 2000, Johnson, 2004). The hyporheic zone is defined as the region located beneath the channel characterized by complex hydrodynamic processes that combine stream water and

groundwater. The resulting fluxes can have significant implications for stream temperature at different spatial and temporal scales.

Figures 3 and 4 are included to show surface heat flux in a relatively unshaded and in a more heavily shaded stream reach respectively. Figure 4 shows an example of the estimated diurnal pattern of the surface heat fluxes in the one of Washington's coastal rivers for the week of August 8-14, 2001. The daily maximum temperatures in a stream are strongly influenced by removal of riparian vegetation because of diurnal patterns of solar short-wave heat flux (Adams and Sullivan, 1989). The solar short-wave flux can be controlled by managing vegetation in the riparian areas adjacent to the stream. Figure 5 shows an example of the estimated diurnal pattern of the surface heat fluxes in a more heavily shaded location in the same river. Shade that is produced by riparian vegetation or topography can reduce the solar short-wave flux. Other processes, such as long-wave radiation, convection, evaporation, bed conduction, or hyporheic exchange also influence the net heat flux into or out of a stream.

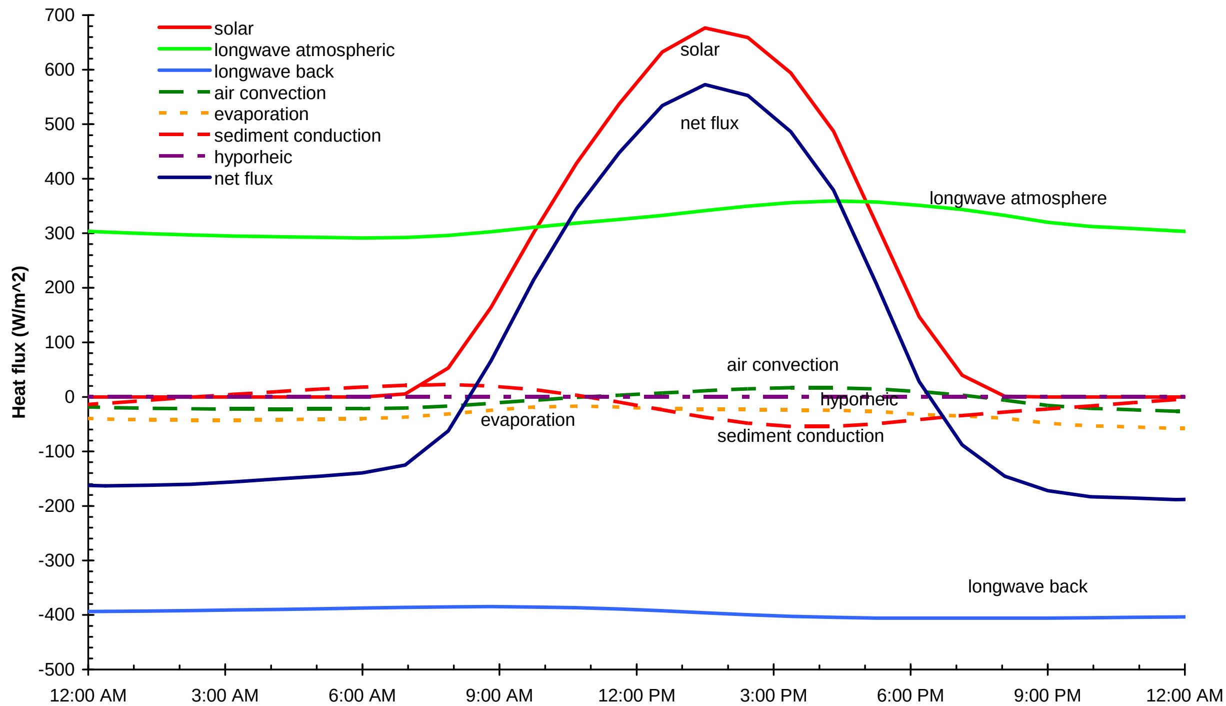

Figure X3. Estimated heat fluxes in a coastal river (Site 3) during August 8-14, 2001 (net heat flux = solar + longwave atmosphere + longwave back + air convection + evaporation + sediment conduction + hyporheic).

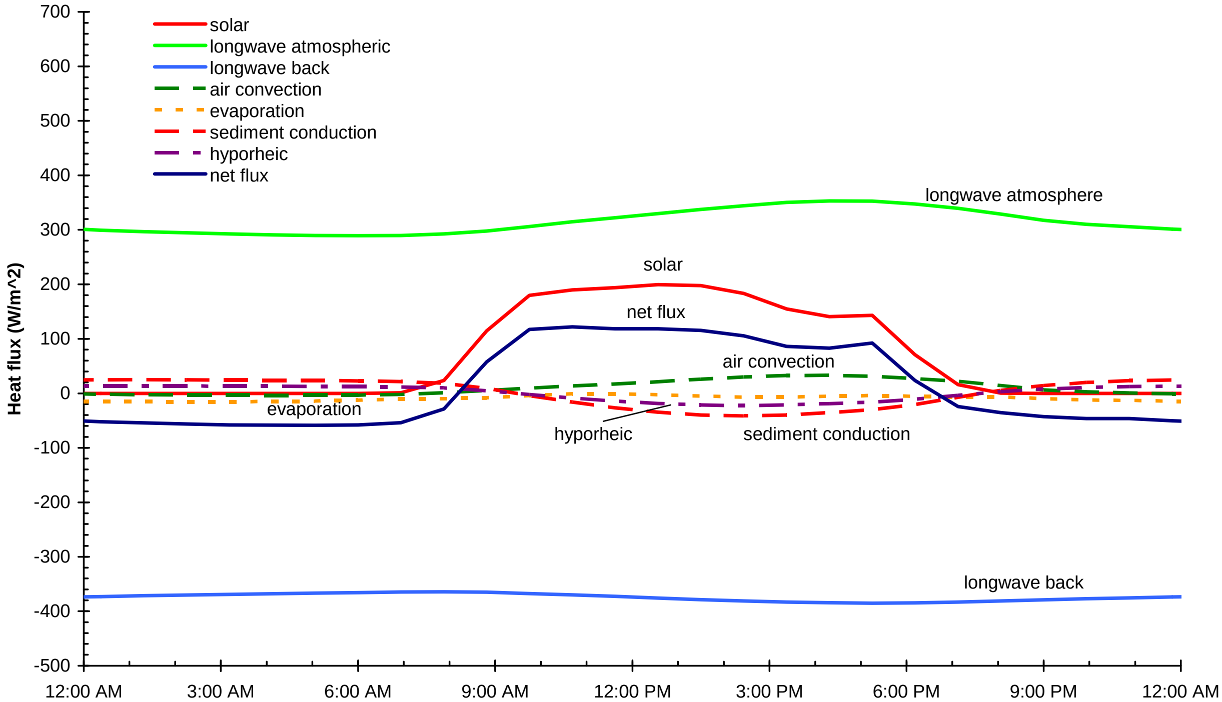

Figure X4. Estimated heat fluxes in a more shaded section of the river during August 8-14, 2001 (net heat flux = solar + longwave atmosphere + longwave back + air convection + evaporation + sediment conduction + hyporheic).

Heat exchange between the stream and the streambed has an important influence on water temperature. The temperature of the streambed is typically warmer than the overlying water at night and cooler than the water during the daylight hours (Figure 5). Heat is typically transferred from the water into the streambed during the day then back into the stream during the night (Adams and Sullivan, 1989). This has the effect of dampening the diurnal range of stream temperature variations without affecting the daily average stream temperature.

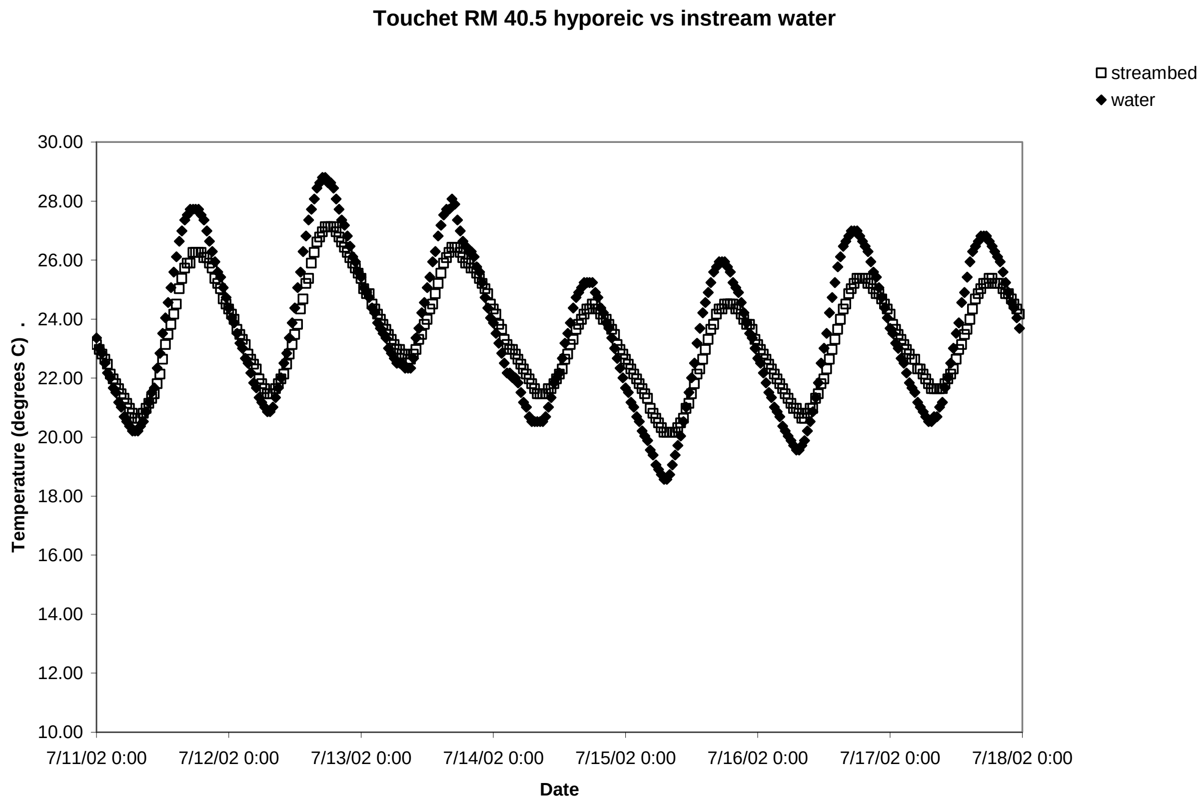

Figure X5. An example of water and streambed temperatures in mid-July in the Touchet River.

The bulk temperature of a vertically mixed volume of water in a stream segment under natural conditions tends to increase or decrease with time during the day according to whether the net heat flux is either positive or negative. When the sun is not shining, the water temperature tends toward the dew-point temperature (Edinger et al., 1974; Brady et al., 1969). The equilibrium temperature of a natural body of water is defined as the temperature at which the water is in equilibrium with its surrounding environment and the net rate of surface heat exchange would be zero (Edinger et al., 1968; Edinger et al., 1974).

The dominant contribution to the seasonal variations in the equilibrium temperature of water is from seasonal variations in the dew-point temperature (Edinger et al., 1974). The main source of hourly fluctuations in water temperature during the day is solar radiation. Solar radiation generally reaches a maximum during the day when the sun is highest in the sky unless cloud cover or shade from vegetation interferes.

The complete heat budget for a stream also accounts for the mass transfer processes which depend on the amount of flow and the temperature of water flowing into and out of a particular volume of water in a segment of a stream. Mass transfer processes in open channel systems can occur through advection, dispersion, and mixing with tributaries and groundwater inflows and outflows. Mass transfer relates to transport of flow volume downstream, instream mixing and the introduction or removal of water from a stream. For instance, flow from a tributary will cause a temperature change if the temperature is different from the receiving water.

Thermal role of riparian vegetation

The role of riparian vegetation in maintaining a healthy stream condition and water quality is well documented and accepted in the scientific literature. Summer stream temperature increases due to the removal of riparian vegetation is well documented (*e.g.*, Holtby, 1988; Lynch et al., 1984; Rishel et al., 1982; Patric, 1980; Swift and Messer, 1971; Brown et al., 1971; and Levno and Rothacher, 1967). These studies generally support the findings of Brown and Krygier (1970) that loss of riparian vegetation results in larger daily temperature variations and elevated monthly and annual temperatures. Adams and Sullivan (1989) also concluded that daily maximum temperatures are strongly influenced by the removal or riparian vegetation because of the effect of diurnal fluctuations in solar heat flux.

Summaries of the scientific literature on the thermal role of riparian vegetation in forested and agricultural areas are provided by Belt et al., 1992; Beschta et al., 1987; Bolton and Monahan, 2001; Castelle and Johnson, 2000; CH2M Hill, 2000; GEI, 2002; Ice, 2001; and Wenger, 1999. All of these summaries recognize that the scientific literature indicates that riparian vegetation plays an important role in controlling stream temperature. The list of important benefits that riparian vegetation has upon the stream temperature includes:

- Near-stream vegetation height, width and density combine to produce shadows that can reduce solar heat flux to the surface of the water
- Riparian vegetation creates a thermal microclimate that generally maintains cooler air temperatures, higher relative humidity, lower wind speeds, and cooler ground temperatures along stream corridors.
- Bank stability is largely a function of near stream vegetation. Specifically, channel morphology is often highly influenced by land-cover type and condition by affecting flood plain and instream roughness, contributing coarse woody debris and influencing sedimentation, stream substrate compositions and stream bank stability.

The warming of water temperatures as a stream flows downstream is a natural process. However, the rates of heating can be dramatically reduced when high levels of shade exist and heat flux from solar radiation is minimized. The overriding justification for increases in shade from riparian vegetation is to minimize the contribution of solar heat flux in stream heating.

There is a natural maximum level of shade that a given stream is capable of attaining, and the importance of shade decreases as the width of a stream increases.

The distinction between reduced heating of streams and actual cooling is important. Shade can significantly reduce the amount of heat flux that enters a stream. Whether there is a reduction in the amount of warming of the stream, maintenance of inflowing temperatures, or cooling of a stream as it flows downstream depends on the balance of all of the heat exchange and mass transfer processes in the stream.

Effective shade

Shade is an important parameter that controls the stream heating derived from solar radiation. Solar radiation has the potential to be one of the largest heat-transfer mechanisms in a stream system. Human activities can degrade near-stream vegetation and/or channel morphology, and in turn, decrease shade. Reductions in stream surface shade have the potential to cause significant increases in heat delivery to a stream system. Stream shade is an important factor in describing the heat budget for the present analysis. Stream shade may be measured or calculated using a variety of methods (Chen, 1996; Chen et al., 1998; Ice, 2001; OWEB, 1999; Teti, 2001; Teti and Pike, 2005).

Shade is the amount of solar energy that is obscured or reflected by vegetation or topography above a stream. Effective shade is defined as the fraction or percentage of the total possible solar radiation heat energy that is prevented from reaching the surface of the water:

$$\text{effective shade} = (J_1 - J_2)/J_1$$

where J_1 is the potential solar heat flux above the influence of riparian vegetation and topography and J_2 is the solar heat flux at the stream surface.

In the Northern Hemisphere, the earth tilts on its axis toward the sun during summer months, allowing longer day length and higher solar altitude, both of which are functions of solar declination (i.e., a measure of the earth's tilt toward the sun) (Figure 6). Geographic position (i.e., latitude and longitude) fixes the stream to a position on the globe, while aspect provides the stream/riparian orientation (direction of streamflow). Near-stream vegetation height, width, and density describe the physical barriers between the stream and sun that can attenuate and scatter incoming solar radiation (i.e., produce shade) (Table 1). The solar position has a vertical component (i.e., solar altitude) and a horizontal component (i.e., solar azimuth) that are both functions of time/date (i.e., solar declination) and the earth's rotation.

While the interaction of these shade variables may seem complex, the mathematics that describes them is relatively straightforward geometry. Using solar tables or mathematical simulations, the potential daily solar load can be quantified. The shade from riparian vegetation can be measured with a variety of methods, including (Ice, 2001, OWEB, 1999; Boyd, 1996; Teti, 2001, Teti and Pike, 2005):

- Hemispherical photography
- Angular canopy densiometer

- Solar pathfinder

Hemispherical photography is generally regarded as the most accurate method for measuring shade, although the equipment that is required is significantly more expensive compared with other methods. Angular canopy densiometers (ACD) and Solar pathfinders provide a good balance of cost and accuracy for measuring the importance of riparian vegetation for preventing increases in stream temperature (Teti, 2001, Beschta et al., 1987, Teti, 2005). Whereas canopy density is usually expressed as a vertical projection of the canopy onto a horizontal surface, the ACD is a projection of the canopy measured at an angle above the horizon at which direct beam solar radiation passes through the canopy. This angle is typically determined by the position of the sun above the horizon during that portion of the day (usually between 10 A.M. and 2 P.M. in mid to late summer) when the potential solar heat flux is most significant. Typical values of the ACD for old-growth stands in western Oregon have been reported to range from 80% to 90%.

Computer programs for the mathematical simulation of shade may also be used to estimate shade from measurements or estimates of the key parameters listed in Table 1 (Ecology 2003a, Chen, 1996, Chen et al., 1998, Boyd, 1996, Boyd and Park, 1998).

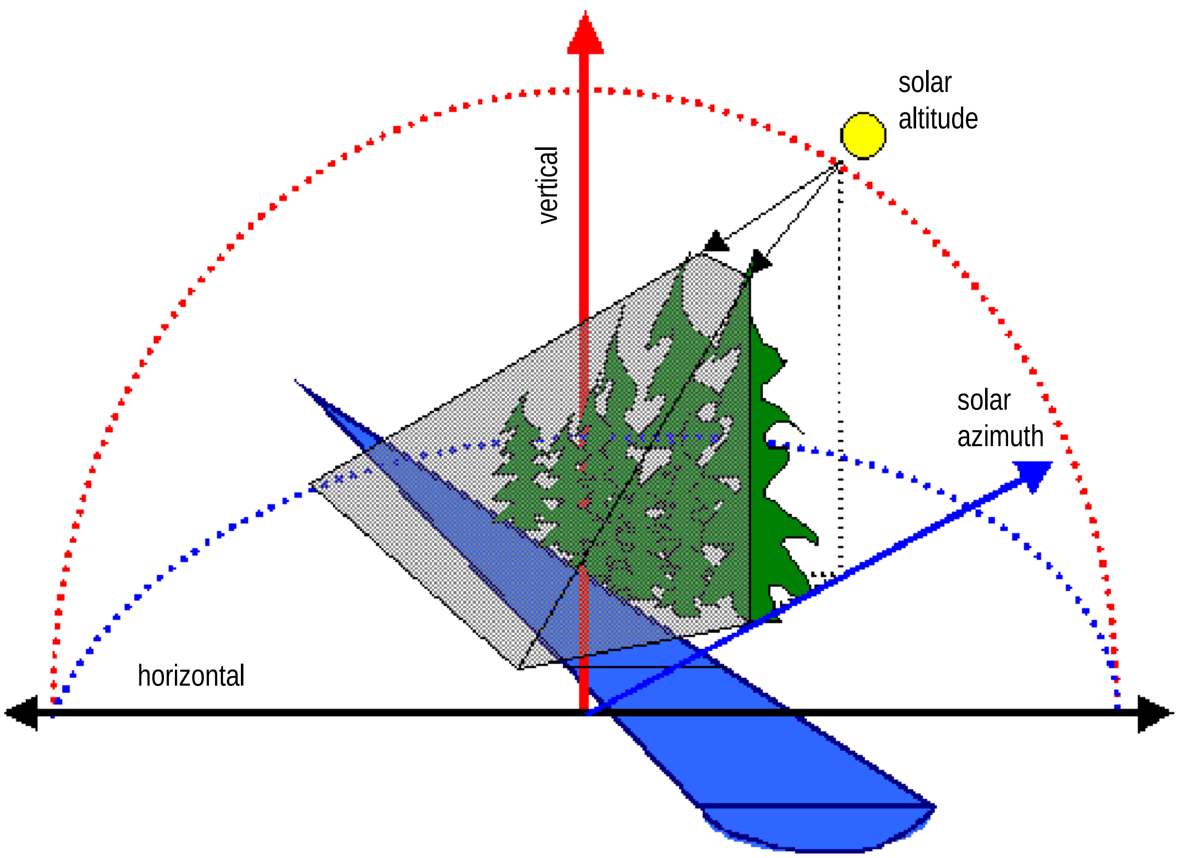

Figure X6. Parameters that affect shade and geometric relationships. Solar altitude is a measure of the vertical angle of the sun's position relative to the horizon. Solar azimuth is a measure of the horizontal angle of the sun's position relative to north.

Table X1. Factors that influence stream shade (bold indicates influenced by human activities).

Description	Parameter
Season/time	Date/time
Stream characteristics	Aspect, **channel width**
Geographic position	Latitude, longitude
Vegetative characteristics	**Riparian vegetation height, width, and density**
Solar position	Solar altitude, solar azimuth

Riparian buffers and effective shade

Trees in riparian areas provide shade to streams and minimize undesirable water temperature changes (Brazier and Brown 1973; Steinblums et al., 1984). The shading effectiveness of riparian vegetation is correlated to riparian area width (Figure 7). The shade as represented by angular canopy density (ACD) for a given riparian buffer width varies over space and time because of differences among site potential vegetation, forest development stages (e.g., height and density), and stream width. For example, a 50-foot-wide riparian area with fully developed trees could provide from 45 to 72 percent of the potential shade in the two studies shown in Figure 7. The Brazier and Brown (1973) shade data show a stronger relationship between ACD and buffer strip width than the Steinblums et al. (1984) data — the r^2 correlation for ACD and buffer width was 0.87 and 0.61 in Brazier and Brown (1973) and Steinblums et al. (1984), respectively. This difference supports the use of the Brazier and Brown curve as a base for measuring shade effectiveness under various riparian buffer proposals. These results reflect the natural variation among old growth sites studied, and show a possible range of potential shade.

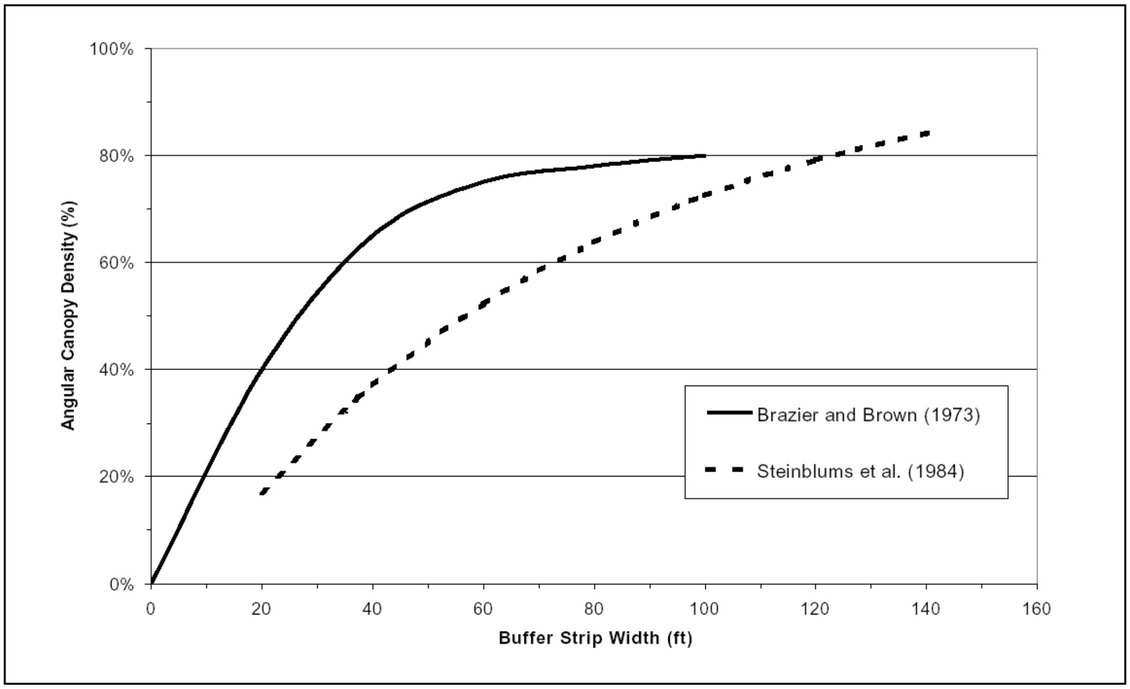

Figure X7. Relationship between angular canopy density and riparian buffer width for small streams in old-growth riparian stands (after Beschta et al., 1987 and CH2M Hill 2000).

Several studies of stream shading report that most of the potential shade comes from the riparian area within about 75 feet (23 m) of the channel (CH2M Hill, 2000; Castelle and Johnson, 2000):

- Beschta et al. (1987) report that a 98-foot-wide (30-m) buffer provides the same level of shading as that of an old-growth stand.
- Brazier and Brown (1973) found that a 79-foot (24-m) buffer would provide maximum shade to streams.
- Steinblums et al. (1984) concluded that a 56-foot (17-m) buffer provides 90 percent of the maximum ACD.
- Corbett and Lynch (1985) concluded that a 39-foot (12-m) buffer should adequately protect small streams from large temperature changes following logging.
- Broderson (1973) reported that a 49-foot-wide (15-m) buffer provides 85 percent of the maximum shade for small streams.
- Lynch et al. (1984) found that a 98-foot-wide (30-m) buffer maintains water temperatures within 2°F (1°C) of their former average temperature in small streams (channel width less than 3 m).

GEI (2002) reviewed the scientific literature related to the effectiveness of buffers for shade protection in agricultural areas in Washington and concluded that buffer widths of 10 m (33 feet) provide nearly 80 percent of the maximum potential shade in agricultural areas. Wenger (1999) concluded that a minimum continuous buffer width of 10-30 m should be preserved or restored along each side of all streams on a municipal or county-wide scale to provide stream temperature control and maintain aquatic habitat. GEI (2002) considered the recommendations of Wenger (1999) to be relevant for agricultural areas in Washington.

Steinblums et al. (1984) concluded that that shade could be delivered to forest streams from beyond 75 feet (22 m) and potentially out to 140 feet (43 m). In some site-specific cases, forest practices between 75 and 140 feet from the channel have the potential to reduce shade delivery by up to 25 percent of maximum. However, any reduction in shade beyond 75 feet would probably be relatively low on the horizon, and the impact on stream heating would be relatively low because the potential solar radiation decreases significantly as solar elevation decreases.

Microclimate - surrounding thermal environment

A secondary consequence of near stream vegetation is its effect on the riparian microclimate. Riparian corridors often produce a microclimate that surrounds the stream where cooler air temperatures, higher relative humidity, and lower wind speeds are characteristic. Riparian microclimates tend to moderate daily air temperatures. Relative humidity increases result from the evapotranspiration that is occurring by riparian plant communities. Wind speed is reduced by the physical blockage produced by riparian vegetation.

Riparian buffers commonly occur on both sides of the stream, compounding the edge influence on the microclimate. Brosofske et al. (1997) reported that a buffer width of at least 150 feet (45 m) on each side of the stream was required to maintain a natural riparian microclimate environment in small forest streams (channel width less than 4 m) in the foothills of the western slope of the Cascade Mountains in western Washington with predominantly Douglas-fir and western hemlock.

Bartholow (2000) provided a thorough summary of literature of documented changes to the environment of streams and watersheds associated with extensive forest clearing. Changes summarized by Bartholow (2000) are representative of hot summer days and indicate the mean daily effect unless otherwise indicated:

- **Air temperature**. Edgerton and McConnell (1976) showed that removing all or a portion of the tree canopy resulted in cooler terrestrial air temperatures at night and warmer temperatures during the day, enough to influence thermal cover sought by elk (Cervus canadensis) on their eastern Oregon summer range. Increases in maximum air temperature varied from 5 to 7ºC for the hottest days (estimate). However, the mean daily air temperature did not appear to have changed substantially since the maximum temperatures were offset by almost equal changes to the minima. Similar temperatures have been commonly reported (Childs and Flint, 1987; Fowler et al., 1987), even with extensive clearcuts (Holtby, 1988). In an evaluation of buffer strip width, Brosofske et al. (1997) found that air temperatures immediately adjacent to the ground increased 4.5ºC during the day and about 0.5ºC at night (estimate). Fowler and Anderson (1987) measured a 0.9ºC air temperature increase in clearcut areas, but temperatures were also 3ºC higher in the adjacent forest. Chen et al. (1993) found similar (2.1ºC) increases. All measurements reported here were made over land instead of water, but in aggregate support about a 2ºC increase in ambient mean daily air temperature resulting from extensive clearcutting.

- **Relative humidity**. Brosofske et al. (1997) examined changes in relative humidity within 17 to 72 m buffer strips. The focus of their study was to document changes along the gradient from forested to clearcut areas, so they did not explicitly report pre- to post-harvest changes at the stream. However, there appeared to be a reduction in relative humidity at the stream of 7% during the day and 6% at night (estimate). Relative humidity at stream sites increased exponentially with buffer width. Similarly, a study by Chen et al. (1993) showed a decrease of about 11% in mean daily relative humidity on clear days at the edges of clearcuts.

- **Wind speed**. Brosofske et al. (1997) reported almost no change in wind speed at stream locations within buffer strips adjacent to clearcuts. Speeds quickly approached upland conditions toward the edges of the buffers, with an indication that wind actually increased substantially at distances of about 15 m from the edge of the strip, and then declined farther upslope to pre-harvest conditions. Chen et al. (1993) documented increases in both peak and steady winds in clearcut areas; increments ranged from 0.7 to 1.2 m/s (estimated).

Thermal role of channel morphology

Changes in channel morphology, namely channel widening, impacts stream temperatures. As a stream widens, the surface area exposed to heat flux increases, resulting in increased energy exchange between a stream and its environment (Chapra, 1997). Further, wide channels are likely to have decreased levels of shade due to the increased distance created between vegetation and the wetted channel and the decreased fraction of the stream width that could potentially be covered by shadows from riparian vegetation. Conversely, narrow channels are more likely to experience higher levels of shade.

Channel widening is often related to degraded riparian conditions that allow increased stream bank erosion and sedimentation of the streambed, both of which correlate strongly with riparian vegetation type and condition (Rosgen 1996). Channel morphology is not solely dependent on riparian conditions. Sedimentation can deposit material in the channel, fill pools and aggrade the streambed, reducing channel depth and increasing channel width.

Channel modification usually occurs during high flow events. Land uses that affect the magnitude and timing of high flow events may negatively impact channel width and depth. Riparian vegetation conditions will affect the resilience of the stream banks/flood plain during periods of sediment introduction and high flow. Disturbance processes may have differing results depending on the ability of riparian vegetation to shape and protect channels. Channel morphology is related to riparian vegetation composition and condition by:

- **Building stream banks**. Traps suspended sediments, encourages deposition of sediment in the flood plain and reduces incoming sources of sediment.
- **Maintaining stable stream banks**. High rooting strength and high stream bank and flood plain roughness prevents stream bank erosion.
- **Reducing flow velocity** (erosive kinetic energy). Supplies large woody debris to the active channel, provides a high pool to riffle ratio and adds channel complexity that reduces shear stress exposure to stream bank soil particles.

Pollutants and Surrogate Measures

Heat loads to the stream are calculated in this TMDL in units of calories per square centimeter per day (cal/cm²/day) or watts per square meter (W/m^2). However, heat loads are of limited value in guiding management activities needed to solve identified water quality problems.

The Hangman Creek temperature TMDL incorporates measures other than “daily loads” to fulfill the requirements of Section 303(d). This TMDL allocates other appropriate measures, or “surrogate measures” as provided under EPA regulations [40 CFR 130.2(i)]. The “Report of the Federal Advisory Committee on the Total Maximum Daily Load (TMDL) Program” (USEPA, 1998) includes the following guidance on the use of surrogate measures for TMDL development:

"When the impairment is tied to a pollutant for which a numeric criterion is not possible, or where the impairment is identified but cannot be attributed to a single traditional "pollutant," the state should try to identify another (surrogate) environmental indicator that can be used to develop a quantified TMDL, using numeric analytical techniques where they are available, and best professional judgment (BPJ) where they are not."

This technical assessment for the Hangman Creek temperature TMDL uses riparian effective shade as a surrogate measure of heat flux to fulfill the requirements of Section 303(d). Effective shade is defined as the fraction of the potential solar shortwave radiation that is blocked by vegetation and topography before it reaches the stream surface. Other factors influencing heat flux and water temperature were also considered, including microclimate, channel geometry, groundwater recharge, and instream flow.

Table X2. Spokane County Conservation District Densiometer Measurements Taken on Hangman Creek, September 20 – 22, 2006.

Site No.	RM	Left Bank				Center Channel				Right Bank				Shade estimate		
		up	left	down	right	up	left	down	right	up	left	down	right	Average	x 1.04	
		72	92	86	48	0	0	0	2	96	88	96	92	56.0	58.2	
		4	8	84	32	0	0	0	20	92	0	48	72	30.0	31.2	
		16	46	4	10	5	0	0	34	96	92	96	96	41.3	42.9	
1	RM 0.6	0	2	0	5	4	0	2	5	56	6	13	96	15.8	16.4	**27.0**
		0	0	0	10	2	0	2	25	35	4	22	32	11.0	11.4	
		0	12	0	4	0	0	0	16	76	12	40	30	15.8	16.5	
		1	19	1	2	0	0	0	10	8	18	48	32	11.6	12.0	
		15	2	0	0	0	1	0	0	0	12	12	48	7.5	7.8	
		0	12	0	0	0	2	0	3	96	96	45	6	21.7	22.5	
		0	0	0	1	0	0	0	1	0	0	0	22	2.0	2.1	
2	RM 3.6	0	0	0	3	0	0	0	1	0	0	8	17	2.4	2.5	**13.7**
		0	0	0	0	0	0	0	2	0	0	0	0	0.2	0.2	
		0	6	49	0	0	0	0	0	96	96	96	96	36.6	38.0	
		50	92	86	5	0	0	0	0	4	4	8	16	22.1	23.0	
		0	38	6	0	0	0	0	0	0	0	0	10	4.5	4.7	
		8	72	43	2	0	0	0	0	0	0	0	0	10.4	10.8	
		24	32	32	12	0	0	0	0	0	0	0	0	8.3	8.7	
3	RM 4.5	60	25	0	0	0	4	0	0	0	0	0	0	7.4	7.7	**5.5**
		0	44	4	0	0	0	0	0	0	0	0	0	4.0	4.2	
		0	10	18	0	0	0	0	0	0	0	0	0	2.3	2.4	
		0	0	0	0	0	0	0	0	0	0	0	0	0.0	0.0	
		46	10	44	6	3	7	3	14	12	6	14	54	18.3	19.0	
		96	96	96	96	6	12	3	38	96	96	96	96	68.9	71.7	
		0	3	0	8	7	6	7	26	38	0	18	72	15.4	16.0	
4	RM 5.7	96	92	90	0	0	0	0	8	2	0	0	14	25.2	26.2	**26.0**
		42	88	2	0	0	18	0	3	1	13	18	11	16.3	17.0	

Site No.	RM	Left Bank				Center Channel				Right Bank				Shade estimate		
		up	left	down	right	up	left	down	right	up	left	down	right	Average	x 1.04	
		4	4	4	9	0	2	0	27	0	1	3	38	7.7	8.0	
		0	8	0	9	0	2	2	28	44	24	76	88	23.4	24.4	
		28	48	0	0	2	0	0	10	25	0	2	5	10.0	10.4	
		2	8	2	0	0	0	0	0	0	0	0	0	1.0	1.0	
		0	86	18	0	0	0	0	0	0	0	0	0	8.7	9.0	
5	RM 8.8	0	0	0	0	0	0	0	0	0	0	0	0	0.0	0.0	**5.7**
		0	0	0	0	0	0	0	0	0	0	0	0	0.0	0.0	
		0	0	0	0	0	0	0	0	70	32	21	84	17.3	17.9	
		0	0	0	0	0	2	3	7	0	0	3	0	1.3	1.3	
		0	34	6	0	0	4	0	0	0	0	0	0	3.7	3.8	
		0	0	0	0	0	0	0	0	10	0	0	0	0.8	0.9	
		0	11	0	0	0	0	0	0	0	0	0	0	0.9	1.0	
6	RM13.8	34	16	0	0	0	0	0	4	0	0	0	0	4.5	4.7	**1.5**
		0	0	0	0	0	0	0	0	0	0	0	0	0.0	0.0	
		0	0	0	0	0	0	0	0	0	0	0	0	0.0	0.0	
		0	0	0	0	0	0	0	0	0	0	0	0	0.0	0.0	
		0	0	0	0	0	0	0	0	0	0	0	0	0.0	0.0	
		0	0	0	0	0	0	0	0	0	0	0	0	0.0	0.0	
		0	0	0	0	0	0	0	0	0	0	0	0	0.0	0.0	
7	RM18.2	0	0	0	0	0	0	0	0	0	0	0	0	0.0	0.0	**2.9**
		0	0	0	0	0	0	0	0	0	0	0	0	0.0	0.0	
		0	0	0	0	0	0	0	0	0	0	0	0	0.0	0.0	
		10	20	10	0	0	0	2	38	27	0	46	85	19.8	20.6	
		1	30	2	26	18	0	6	18	50	0	14	59	18.7	19.4	
		0	6	0	12	2	0	10	42	60	12	44	92	23.3	24.3	
		6	52	12	0	0	7	0	6	10	0	9	26	10.7	11.1	
8	RM18.7	32	0	0	28	0	0	0	0	12	0	8	52	11.0	11.4	**12.3**
		0	0	0	0	0	0	0	0	84	17	5	78	15.3	15.9	
		4	8	0	0	0	0	0	0	0	0	0	0	1.0	1.0	
		14	21	0	0	0	0	0	0	0	0	0	0	2.9	3.0	
		6	0	0	0	0	0	0	0	0	0	0	0	0.5	0.5	
		0	0	0	0	0	0	0	0	0	0	0	0	0.0	0.0	
		0	16	2	0	0	0	0	0	0	0	0	0	1.5	1.6	
9	RM 20.2	3	7	0	0	0	0	0	0	0	0	0	0	0.8	0.9	**0.4**
		0	0	0	0	0	0	0	0	0	0	0	0	0.0	0.0	
		0	0	0	0	0	0	0	0	0	0	0	0	0.0	0.0	
		0	0	0	0	0	0	0	0	0	0	0	0	0.0	0.0	
		0	0	0	0	0	0	0	0	0	0	0	0	0.0	0.0	
		0	0	0	0	0	0	0	0	0	0	0	0	0.0	0.0	

Site No.	RM	Left Bank				Center Channel				Right Bank				Shade estimate		
		up	left	down	right	up	left	down	right	up	left	down	right	Average	x 1.04	
		0	0	0	0	0	0	0	0	0	0	0	0	0.0	0.0	
10	RM 22.5	0	0	0	0	0	0	0	0	0	0	0	0	0.0	0.0	**0.4**
		0	0	0	0	0	0	0	0	0	0	0	0	0.0	0.0	
		0	0	0	0	0	0	0	0	0	0	0	0	0.0	0.0	
		23	7	3	0	0	2	0	0	0	0	0	0	2.9	3.0	
		0	0	0	0	0	0	0	2	2	0	0	18	1.8	1.9	
		0	2	0	0	0	0	0	2	8	0	0	0	1.0	1.0	
		0	3	1	0	0	2	0	3	10	0	12	38	5.8	6.0	
11	RM 29.2	2	7	0	2	0	0	4	8	66	7	61	96	21.1	21.9	**9.4**
		2	15	0	4	0	8	2	24	20	0	26	55	13.0	13.5	
		0	4	0	3	6	0	7	12	17	0	15	28	7.7	8.0	
		6	0	0	0	2	2	12	21	27	1	42	46	13.3	13.8	
		21	0	0	0	2	2	0	0	0	0	0	0	2.1	2.2	
		0	0	0	0	0	0	0	0	0	0	0	0	0.0	0.0	
		0	1	2	0	0	0	3	4	96	0	58	32	16.3	17.0	
12	RM 31	0	20	0	2	5	0	0	6	25	0	0	0	4.8	5.0	**4.1**
		1	0	0	0	0	2	0	0	15	0	0	34	4.3	4.5	
		0	0	0	0	0	0	0	0	0	0	0	0	0.0	0.0	
		0	0	0	0	0	0	0	0	0	0	0	0	0.0	0.0	
		0	0	0	0	0	0	0	0	0	0	0	8	0.7	0.7	
		0	0	0	0	0	0	0	0	0	0	0	18	1.5	1.6	
		0	0	0	0	0	0	0	0	0	0	0	0	0.0	0.0	
13	RM 32.9	0	0	0	0	0	0	0	0	0	0	0	6	0.5	0.5	**2.2**
		0	0	0	0	0	0	0	0	0	0	0	0	0.0	0.0	
		8	7	0	0	0	0	0	0	0	4	24	4	3.9	4.1	
		2	29	25	0	0	22	0	0	10	13	0	0	8.4	8.8	
		96	96	96	88	0	0	0	24	0	2	0	0	33.5	34.8	
		0	22	2	0	0	0	0	0	0	6	0	0	2.5	2.6	
		20	92	34	0	0	26	15	0	0	13	0	0	16.7	17.3	
14	RM 35.5	8	16	0	0	2	8	2	0	0	1	8	0	3.8	3.9	**9.4**
		6	24	0	0	0	6	0	0	0	7	1	0	3.7	3.8	
		0	24	0	0	0	4	0	0	0	6	0	0	2.8	2.9	
		0	2	0	0	0	0	0	0	0	0	0	0	0.2	0.2	
		0	0	0	0	0	0	0	0	0	0	0	0	0.0	0.0	
		0	0	0	0	0	0	0	0	0	0	0	0	0.0	0.0	
		0	0	0	0	0	0	0	0	0	0	0	0	0.0	0.0	
15	RM 37	0	0	0	0	0	0	0	0	0	0	0	0	0.0	0.0	**0.0**
		0	0	0	0	0	0	0	0	0	0	0	0	0.0	0.0	

Site No.	RM	Left Bank				Center Channel				Right Bank				Shade estimate		
		up	left	down	right	up	left	down	right	up	left	down	right	Average	x 1.04	
		0	0	0	0	0	0	0	0	0	0	0	0	0.0	0.0	
		0	0	0	0	0	0	0	0	0	0	0	0	0.0	0.0	
		0	0	2	0	0	0	0	2	0	4	0	0	0.7	0.7	
		4	12	7	0	8	10	2	0	24	0	12	92	14.3	14.8	
		0	15	1	3	0	0	0	0	0	0	16	32	5.6	5.8	
16	RM 38	6	2	1	2	2	6	0	3	0	0	0	14	3.0	3.1	**7.5**
		3	3	6	7	0	2	0	8	8	2	2	26	5.6	5.8	
		1	4	0	0	0	0	0	0	12	0	18	26	5.1	5.3	
		3	6	4	0	0	0	0	0	12	1	80	92	16.5	17.2	
		16	64	22	0	4	8	0	8	15	5	14	56	17.7	18.4	
		16	38	2	0	0	12	0	0	5	1	1	12	7.3	7.5	
		0	8	2	12	0	8	2	12	6	1	0	2	4.4	4.6	
17	RM 39.5	0	22	0	0	2	4	0	2	1	2	5	7	3.8	3.9	**9.5**
		0	38	12	0	0	20	16	4	0	6	1	9	8.8	9.2	
		20	81	20	0	4	34	3	6	0	20	1	2	15.9	16.6	
		1	11	4	0	0	10	0	0	1	2	1	44	6.2	6.4	
		1	5	0	6	0	0	0	0	0	0	1	0	1.1	1.1	
		0	0	4	2	0	0	0	0	3	1	0	0	0.8	0.9	
		12	54	10	0	0	0	0	0	0	0	0	0	6.3	6.6	
18	RM 41.6	0	0	0	0	0	0	0	0	0	0	0	0	0.0	0.0	**1.9**
		0	0	0	0	0	0	0	0	0	1	0	0	0.1	0.1	
		0	0	0	0	0	8	8	8	0	0	0	0	2.0	2.1	
		2	4	10	8	0	0	0	0	0	2	0	0	2.2	2.3	
		2	52	44	0	0	2	0	0	0	0	0	3	8.6	8.9	
		56	96	48	4	0	16	0	0	4	6	15	16	21.8	22.6	
		18	26	2	0	0	4	0	13	68	4	8	66	17.4	18.1	
19	RM 47	30	80	4	4	2	24	0	5	6	2	13	75	20.4	21.2	**18.4**
		36	84	48	10	0	0	0	5	15	0	1	41	20.0	20.8	
		48	80	30	4	0	8	4	10	15	3	18	89	25.8	26.8	
		4	20	2	0	7	0	0	9	48	0	0	32	10.2	10.6	

Bankfull width (m)	Effective shade from vegetation (percent) at the stream center at various stream aspects (degrees from N)			Daily average global solar short-wave radiation (W/m2) at the stream center at various stream aspects (degrees from N)		
	0 and 180 deg aspect	45, 135, 225, and 315 deg aspect	90 and 270 deg aspect	0 and 180 deg aspect	45, 135, 225, and 315 deg aspect	90 and 270 deg aspect
1	97.6%	97.7%	98.1%	7	7	6
2	92.0%	92.3%	95.7%	24	23	13
3	84.7%	84.8%	90.1%	47	46	30
4	78.2%	77.5%	77.5%	66	68	68
5	72.5%	71.2%	67.0%	84	88	100
6	67.3%	65.8%	57.5%	100	104	129
7	62.8%	61.0%	49.9%	113	119	152
8	59.0%	56.9%	44.2%	125	131	170
9	55.6%	53.3%	39.7%	135	142	183
10	52.6%	50.1%	36.1%	144	152	194
12	47.3%	44.6%	30.6%	160	169	211
14	42.9%	40.1%	26.7%	174	182	223
16	39.2%	36.4%	23.7%	185	194	232
18	36.1%	33.3%	21.4%	194	203	239
20	33.4%	30.6%	19.5%	203	211	245
25	28.1%	25.5%	16.0%	219	227	255
30	24.2%	21.8%	13.7%	231	238	263
35	21.3%	19.1%	12.0%	240	246	268
40	18.9%	16.9%	10.6%	247	253	272
45	17.1%	15.2%	9.6%	252	258	275
50	15.5%	13.8%	8.7%	257	262	278
55	14.2%	12.6%	8.0%	261	266	280
60	13.1%	11.6%	7.4%	264	269	282

Table _. Effective shade and solar radiation outcomes for various combinations of stream metrics (width and aspect) based on Hangman Creek maximum system potential vegetation estimates.

Table x. Hangman Creek Heat Load Allocations and shade requirements by kilometer from the Idaho-Washington border to the mouth.

Distance from upstream segment boundary (Km)	Distance to downstream segment boundary (Km)	Current shade condition (%)	System potential shade	Increase in % shade needed	Landmark RM station	Load allocation for daily average shortwave solar radiation on August 1 (watts/m2)
1	2	21%	56%	35%		137.5
2	3	27%	67%	40%		102.0
3	4	23%	66%	43%		106.3
4	5	11%	47%	36%		166.7
5	6	18%	59%	41%		128.9
6	7	20%	58%	38%	ID-WA border	131.3
7	8	25%	52%	27%		149.6
8	9	22%	54%	32%		144.4
9	10	22%	54%	32%		143.6
10	11	11%	45%	34%	Tekoa	172.9
11	12	19%	60%	41%	Little Hangman	125.8
12	13	18%	56%	37%	Tekoa	139.1
13	14	26%	68%	42%		100.3
14	15	30%	67%	37%		104.0
15	16	19%	62%	43%		119.8
16	17	14%	43%	29%		179.7
17	18	11%	48%	37%		162.0
18	19	9%	39%	30%		191.0
19	20	17%	50%	33%		155.3
20	21	27%	43%	17%		178.0
21	22	11%	47%	36%		167.0
22	23	18%	49%	31%	Cove Creek	160.4
23	24	15%	44%	29%	Latah	176.5
24	25	11%	46%	34%		170.4
25	26	12%	47%	35%		165.5
26	27	9%	42%	33%		180.7
27	28	9%	39%	30%		189.9
28	29	10%	35%	25%		203.3
29	30	14%	53%	39%		147.8
30	31	7%	21%	14%		247.1
31	32	14%	41%	27%		186.1
32	33	14%	47%	33%		166.5
33	34	7%	25%	17%		236.0
34	35	7%	37%	30%		196.9
35	36	10%	41%	31%		184.7
36	37	4%	24%	20%	Waverly	239.1

Distance from upstream segment boundary (Km)	Distance to downstream segment boundary (Km)	Current shade condition (%)	System potential shade	Increase in % shade needed	Landmark RM station	Load allocation for daily average shortwave solar radiation on August 1 (watts/m2)
37	38	9%	39%	30%		192.1
38	39	7%	21%	14%		247.1
39	40	18%	54%	37%		142.4
40	41	9%	29%	20%		221.6
41	42	11%	45%	33%		173.5
42	43	7%	33%	26%		209.6
43	44	14%	44%	31%		173.8
44	45	5%	21%	16%	Rattler Run	247.4
45	46	6%	26%	20%		231.4
46	47	7%	31%	24%		214.4
47	48	5%	31%	25%		216.2
48	49	7%	32%	25%		212.2
49	50	12%	33%	21%		209.7
50	51	17%	37%	20%		197.8
51	52	11%	21%	10%		247.5
52	53	22%	29%	7%		221.8
53	54	28%	48%	19%		163.5
54	55	19%	33%	15%		207.9
55	56	20%	37%	17%		196.5
56	57	16%	44%	28%		175.8
57	58	7%	33%	26%		209.3
58	59	9%	39%	29%		190.5
59	60	13%	43%	30%		177.4
60	61	23%	59%	36%		127.3
61	62	16%	42%	26%		180.7
62	63	6%	30%	24%	Latah Road	219.0
63	64	6%	23%	18%		239.3
64	65	10%	23%	13%		240.4
65	66	12%	24%	12%	Rock Creek	236.4
66	67	5%	29%	24%	Spangle Creek	221.9
67	68	13%	34%	21%	Duncan Road	206.6
68	69	10%	34%	24%	California Cr.	206.3
69	70	17%	35%	18%		203.3
70	71	8%	35%	27%		202.7
71	72	16%	50%	34%		156.4
72	73	13%	38%	25%		194.6
73	74	14%	31%	17%		215.1
74	75	14%	45%	30%		172.0
75	76	7%	28%	21%		225.2
76	77	11%	29%	18%	Hangman Val. GC	222.1
77	78	9%	34%	26%		204.3

Distance from upstream segment boundary (Km)	Distance to downstream segment boundary (Km)	Current shade condition (%)	System potential shade	Increase in % shade needed	Landmark RM station	Load allocation for daily average shortwave solar radiation on August 1 (watts/m2)
78	79	7%	21%	14%		245.9
79	80	9%	22%	13%		243.9
80	81	14%	38%	23%		193.4
81	82	7%	28%	21%		223.1
82	83	16%	41%	24%		184.1
83	84	12%	33%	21%		207.2
84	85	13%	39%	27%		188.7
85	86	6%	23%	18%		239.1
86	87	26%	37%	11%		195.9
87	88	27%	42%	15%		180.5
88	89	9%	39%	29%		191.2
89	90	11%	24%	13%		237.2
90	91	14%	32%	18%	Marshall Creek	212.4
91	92	26%	45%	19%		171.8
92	93	19%	50%	32%		154.3
93	94	23%	56%	33%		136.0
94	95	18%	56%	38%		136.9
95	96	19%	48%	29%	USGS Gage	161.9
96	97	22%	31%	10%		213.0
97	97.6	6%	14%	7%		268.6

Appendix x. Original and Adjusted Total Phosphorus Data Collected at Ecology Station 56A070 – Hangman Creek at Mouth.

The total phosphorus data collected from the long-term station Hangman Creek at Mouth (56A070) by the Washington Department of Ecology at were analyzed in the laboratory using a series of different methods from 1996 to the present. A statewide review of phosphorus data collected during this period suggested systematic biases were present and were strongly based on analytical technique. A review paper recommended that project managers review total phosphorus data for their projects and decide if data adjustments are needed.

Hangman Creek total phosphorus data were adjusted after data trends were noticed that coincided with changes in analytical method. The following table contains the original and adjusted data. The data were adjusted in the following ways:

- Samples analyzed in column 'TP 1' from October 1996 to January 1999 used a manual digestion and colorimetric technique. These data were not adjusted.
- Samples in column 'TP 2' were analyzed from February 1999 to September 2003 using an in-line digestion method and Lachat detection system ( ). Data from this period were found to be biased high by about 0.012 mg/L when concentrations were at 0.100 mg/L or more. Data were adjusted by subtracting 0.012 mg/L from each of the original results.
- The second set of samples in column 'TP 1' from October 2003 to September 2006 were analyzed with an inductively couple plasma and mass spectrometry (ICP/MS) method ( ). The data from this period were found to be biased low. A regression equation was used to adjust this set of data: log(Adjusted TP) = 0.949 *log(original TP) + 0.169. The data are still considered to be somewhat deficient in accounting for suspended solids related TP.

Date	TP 1		TP 2		Adjusted TP	
	mg/L		mg/L		mg/L	
08-Oct-96	0.045				0.045	
05-Nov-96	0.037				0.037	
03-Dec-96	0.166	J			0.166	J
14-Jan-97	0.201				0.201	
04-Feb-97	0.108	J			0.108	J
04-Mar-97	0.369				0.369	
08-Apr-97	0.321				0.321	
06-May-97	0.223				0.223	
03-Jun-97	0.238				0.238	
08-Jul-97	0.093				0.093	
05-Aug-97	0.096				0.096	
09-Sep-97	0.097				0.097	
06-Oct-97	0.088				0.088	
03-Nov-97	0.047				0.047	
08-Dec-97	0.084				0.084	
05-Jan-98	0.116				0.116	
02-Feb-98	0.138				0.138	

02-Mar-98	0.099				0.099	
14-Apr-98	0.08				0.08	
04-May-98	0.072				0.072	
08-Jun-98	0.104				0.104	
06-Jul-98	0.089				0.089	
03-Aug-98	0.045				0.045	
14-Sep-98	0.041				0.041	
05-Oct-98	0.029				0.029	
02-Nov-98	0.033				0.033	
07-Dec-98	0.198				0.198	
11-Jan-99	1.74				1.74	
08-Feb-99			0.349		0.337	
08-Mar-99			0.141		0.129	
05-Apr-99			0.1		0.088	
03-May-99			0.068		0.056	
07-Jun-99			0.089		0.077	
12-Jul-99			0.056		0.044	
09-Aug-99			0.072		0.06	
13-Sep-99			0.06		0.048	
10-Oct-99			0.049		0.037	
14-Nov-99			0.053		0.041	
12-Dec-99			0.128		0.116	
09-Jan-00			0.114		0.102	
06-Feb-00			0.218		0.206	
12-Mar-00			0.183		0.171	
09-Apr-00			0.07		0.058	
07-May-00			0.065		0.053	
11-Jun-00			0.058		0.046	
09-Jul-00			0.053		0.041	
06-Aug-00			0.074		0.062	
10-Sep-00			0.077		0.065	
09-Oct-00			0.038		0.026	
13-Nov-00			0.048		0.036	
08-Jan-01			0.044		0.032	
12-Feb-01			0.158		0.146	
12-Mar-01			0.195		0.183	
09-Apr-01			0.085		0.073	
14-May-01			0.1		0.088	
11-Jun-01			0.056		0.044	
09-Jul-01			0.052	J	0.04	J
06-Aug-01			0.031		0.019	
10-Sep-01			0.03	J	0.018	J
14-Oct-01			0.032	J	0.02	J
04-Nov-01			0.033	J	0.021	J
02-Dec-01			0.041		0.029	
13-Jan-02			0.168		0.156	
12-Feb-02			0.16		0.148	
09-Apr-02			0.075		0.063	
13-May-02			0.026		0.014	
04-Jun-02			0.043		0.031	
16-Jul-02			0.035		0.023	
13-Aug-02			0.03		0.018	
10-Sep-02			0.037		0.025	

13-Oct-02			0.036		0.024	
12-Nov-02			0.035		0.023	
16-Dec-02			0.049		0.037	
06-Jan-03			0.116		0.104	
03-Feb-03			0.176		0.164	
03-Mar-03			0.107		0.095	
07-Apr-03			0.09		0.078	
05-May-03			0.053		0.041	
02-Jun-03			0.053		0.041	
07-Jul-03			0.037		0.025	
04-Aug-03			0.05		0.038	
08-Sep-03			0.069		0.057	
07-Oct-03	0.013				0.024	
05-Nov-03	0.016				0.029	
09-Dec-03	0.0163				0.030	
10-Feb-04	0.0732				0.123	
09-Mar-04	0.0815				0.137	
13-Apr-04	0.0215				0.039	
04-May-04	0.0188				0.034	
15-Jun-04	0.0225				0.040	
13-Jul-04	0.021				0.038	
03-Aug-04	0.0139				0.026	
15-Sep-04	0.0179				0.032	
10/6/2004	0.0142				0.026	
11/3/2004	0.0146				0.027	
12/8/2004	0.0758				0.128	
1/5/2005	0.0462				0.080	
2/9/2005	0.0587				0.100	
3/16/2005	0.0188				0.034	
4/6/2005	0.0750				0.126	
5/4/2005	0.0264				0.047	
6/8/2005	0.0400				0.070	
7/13/2005	0.0304				0.054	
8/3/2005	0.0213				0.038	
9/14/2005	0.0108				0.020	
10/5/2005	0.0144				0.026	
11/9/2005	0.0171				0.031	
1/11/2006	0.5840				0.886	
2/8/2006	0.0976				0.162	
3/8/2006	0.1170				0.193	
4/12/2006	0.0871				0.146	
5/3/2006	0.0301				0.053	
6/7/2006	0.0526				0.090	
7/12/2006	0.0241				0.043	
8/9/2006	0.0274				0.049	
9/13/2006	0.0156				0.028	

Multiple Regression Model by Cohn (1988)

The method employs a statistical regression model, where the constituent concentrations are estimated based on streamflow and time/season. The application requires daily value streamflow records and unit values of constituent concentrations.

$$\ln[L] = \beta_0 + \beta_1 \ln[Q] + \beta_2 \ln[Q]^2 + \beta_3 T + \beta_4 T^2 + \beta_5 \sin[2*\pi T] + \beta_6 \cos[2*\pi T] + \varepsilon$$

Where

L is the water quality constituent concentration, e.g. phosphorus, total suspended solids, etc.
Q is the daily discharge
T is time, expressed in years

The parameters β_1 and β_2 in the equation correspond to variability related to flow dependence, the next pair correspond to time trends, and the third pair are used to fit a first-order Fourier series to the seasonal component of variability.

Overview of the Watershed Analysis Risk Management Framework (WARMF) Model

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Appendix X. Marketing Elements for Water Quality Issues Evaluated by the TMDL Advisory Committee

Improving water quality conditions requires changing our behaviors that negatively affect our streams. In order to effectively change behaviors it is important to identify the barriers and benefits to changing to the new behavior and the barriers and benefits to the current behavior. Agencies working to change behaviors need to increase the benefits of the desired behavior and reduce barriers preventing the adoption of the desired behavior. This is the basis for community-based marketing.

The TMDL advisory committee applied these marketing principles to the water quality issues identified as affecting the streams in the Hangman Creek Watershed. For each of the issues, the current practice(s) and the desired practice(s) were identified. In general, the desired practice is a management practice that tends to improve water quality for the issue being discussed. Along with the desired practices, both barriers and benefits for continuing the current practices, and barriers and benefits for changing to the desired practices were evaluated.

The barriers and benefits common to most of the issues and practices are listed below. There were several issues where the desired practice and current practice could be switched, depending on a person's point of view. It was recognized that most issues would benefit from continued, if not more public education.

<u>General benefits or motivations common to most **desired practices** were identified as</u>:
Improves water quality.
Decrease any penalties associated with water quality violations.
It is the right thing to do, may influence neighbors.

<u>General costs or barriers common to most **desired practices** were identified as</u>:
Cost more money.
Inconvenience, need more equipment or infrastructure.
Increased maintenance.
Takes land out of production.

<u>General benefits or motivations common to most **current practices** were identified as</u>:
Easy, convenient.
Costs less, cheaper.
No government interference.
More land in production, especially for leased land.

<u>General costs or barriers common to most **current practices** were identified as</u>:
Possible Fines, enforcement actions.
Future regulations.
Contributing to pollution.
Missing opportunities for financial assistance.

The anticipated approaches to meet load allocations are outlined under Implementations Activities. The approaches that are expected to be used include the implementation of sediment reducing and livestock management BMPs, along with an information and education program. As incentive and implementation programs for BMPs are developed, large-scale programs will continue to assess the benefits of the implementation. Schedules and milestones for the implementation will be developed during the Detailed Implementation Plan formation.

Issue 1: Sediment/nutrients from agricultural operations

BMP	Parameters Addressed	Potential Problems to Implement BMP
No Till/ Minimum Till	Sediment, Nutrients Turbidity	Equipment change, change in farm plans and practices, owner vs. leaser, initial decrease in yields, increase in chemical use, colder soil temperature, fields stay wetter.
Riparian Buffers	Sediment, Nutrients, Temperature, DO	Loss of highly productive land, harder to farm, weeds, costs in time and money to establish, potential wildlife fecal inputs.
Sediment Basins	Sediment, Nutrients	Cost to install, have to be able to farm around, may need to clean out, small loss of farmland.
Grassed Waterway	**Sediment** Nutrients	Hay usually produces less return than other crops, maintenance, limited habitat, establishment time can be long.
Filter Strips	Sediment Nutrients Temperature	Reduces farmable land, weed problems, requires maintenance.
Divided Slopes	**Sediment** Nutrients	Harder to farm, may not work with all crops, increased turning time, pesticide and herbicide application harder.

<u>Issue 2: Sediment/fecal from livestock and wildlife</u>

BMP	Parameters Addressed	Potential Problems to Implement BMP
Riparian Buffer	Sediment Nutrients Fecal	Requires new water access or source, more maintenance, weed problems.
Livestock Fencing	Sediment Nutrients Fecal	Requires new water access or source, more maintenance, potential problem during high water events.
Manure Retention Facilities	**Nutrients** Fecal	Initial costs, requires truck access and space may be a problem.
Off-Creek Watering	Sediment Nutrients Fecal	Need year round water source, may need numerous sources if lots of livestock, maintenance.
Intensive Management Grazing	Sediment Nutrients Fecal	Requires more land.
Nutrient/fecal Management	Sediment Nutrients Fecal	Requires soil testing, may require more equipment.

<u>Issue 3: Nutrients/Chemicals from Residential uses</u>

BMP	Parameters Addressed	Potential Problems to Implement BMP
Fertilizer Management	Nutrient	Need better education at local level.
Septic Maintenance	Nutrients Fecal	Increased maintenance costs.
Pet waste Management	Nutrients Fecal	Need to have bags along when walking pets, need a place to put waste.
Proper Household Chemical Use and Disposal	Chemicals Nutrients	Need local recycle centers where hazardous household waste can be taken.
Proper Pesticide/Herbicide Use and Disposal	Chemicals Nutrients	Need local recycle centers where hazardous household waste can be taken.
No Lawn Clipping Dumping in Streams	Chemicals Nutrients	Need another way to compost or dispose of yard waste.

Follow Shoreline Management	Sediment Chemicals Nutrients	Less access to the water, loss of view, weed problems.

<u>Issue 4: Sediment from agricultural field ditches</u>

BMP	Parameters Addressed	Potential Problems to Implement BMP
Uphill Plowing	Sediment Nutrients	Uses more fuel, harder to plow.
Ditch Maintenance	Sediment Nutrients	Increased time and costs.
Proper Construction/ Engineering	Sediment Nutrients	Dependent on upstream land uses remaining the same over time, may require assistance from NRCS or conservation district.
Grassed Waterway Conversion	Sediment Nutrients	Could take more land out of primary production.

<u>Issue 5: Nutrients/fecal from Improper Functioning Septic Systems</u>

BMP	Parameters Addressed	Potential Problems to Implement BMP
Educate on the negative affects of garbage disposals	Fecal Chemicals Nutrients	Desired in kitchens, may already exist
Have system inspections every 1-3 year	Fecal Chemicals Nutrients	Cost of inspection/pumping done on a regular basis. Need to target older systems near streams
Take roof drains out of system/away from drainfield	Fecal Chemicals Nutrients	May not have a good area to drain roof system to
Educate about proper items to go into systems	Fecal Chemicals Nutrients	Reaching people with septic systems, not enough places for disposal of household hazardous wastes
Comment on new developments through SEPA	Fecal Chemicals Nutrients	SCCD may not be on all lists for review. Public may not be aware of opportunity to comment
Replace or repair failing systems	Fecal Chemicals Nutrients	High cost, many people may not know systems need to be replaced

Issue 6: Sediment from Gravel and Summer Roads

BMP	Parameters Addressed	Potential Problems to Implement BMP
Pave Roads	Sediment	Initial cost to pave and maintenance.
Close Roads in Winter	Sediment	Less access to fields, may require gates on roads, more maintenance.
Increased Grading & graveling	Sediment	Increased costs for the county.

Issue 7: Sediment from Sheer or Undercut Banks

BMP	Parameters Addressed	Potential Problems to Implement BMP
Live Plantings	Sediment Erosion Temperature	Not an instant fix, may need time to fully develop, requires maintenance.
Reshape Bank and Plantings	Sediment Erosion Temperature	Increased cost, must remove cut bank material from floodplain, erosion potential for first few years, loss of land.
Engineered Structures	Sediment Erosion	Provides less habitat, cost more to install, need permits.

Issue 8: Sediment from Storm Water

BMP	Parameters Addressed	Potential Problems to Implement BMP
Road Runoff to Basin	Sediment Chemicals	Increased cost, increase land use near roads, maintenance of ditches

Issue 9: Forestry Management

BMP	Parameters Addressed	Potential Problems to Implement BMP
Selective Harvest	**Sediment**	Less income, need skilled logger, may be topography dependent.
Stream Crossings	Sediment	Cost more, may have to remove after completion.

Streamside Management Zones	Sediment Temperature	Less trees available for logging, harder to remove logs.
Proper Road Planning & Construction	Sediment	May take longer to plan, could increase road costs.

Issue 10: Sediment from Roadside Ditching

BMP	Parameters Addressed	Potential Problems to Implement BMP
Design Vegetated Ditches	Sediment Chemicals	Weeds, may need maintenance of vegetation, may need more space to install, some engineering required.
Install Detention Basins	Sediment Chemicals	Weeds, may need maintenance, some engineering required.

Appendix x. Response to Public Comments

This appendix will be completed after the Public Comment period.

Parking lot for language – delete before publishing

Outline for Hangman Creek TMDL Water Quality Issues

A. Sediment

1. Livestock
2. Agricultural Field Ditches
3. Gravel/Summer Roads
4. Sheer or Undercut Banks
5. Stormwater- Rural
6. Stormwater- City
7. City Stormwater, not entering drains
8. County Ditch Dredging
9. Private Ditch Dredging

B. Chemicals

1. Local Sources (Small Scale Applications: Ditch Spraying, homeowners)
2. De-Icer
3. Agricultural Application

C. Enforcement

1. County enforcement
2. State enforcement
3. Development/Permits

D. Wetlands/Riparian

1. New Wetland Construction
2. Maintenance of Existing
3. Maintain Riparian Areas

E. Other Issues

1. Return Stream to Original Channel
2. Drain Tile
3. Rock Pit/blasting
4.Increase Stream Flows
5. Invasive Aquatic Plants
6. Beaver Ponds, Fecal Coliform Additions
7. Fecal Coliform from Livestock (see #1 above)
8. Forestry impacts